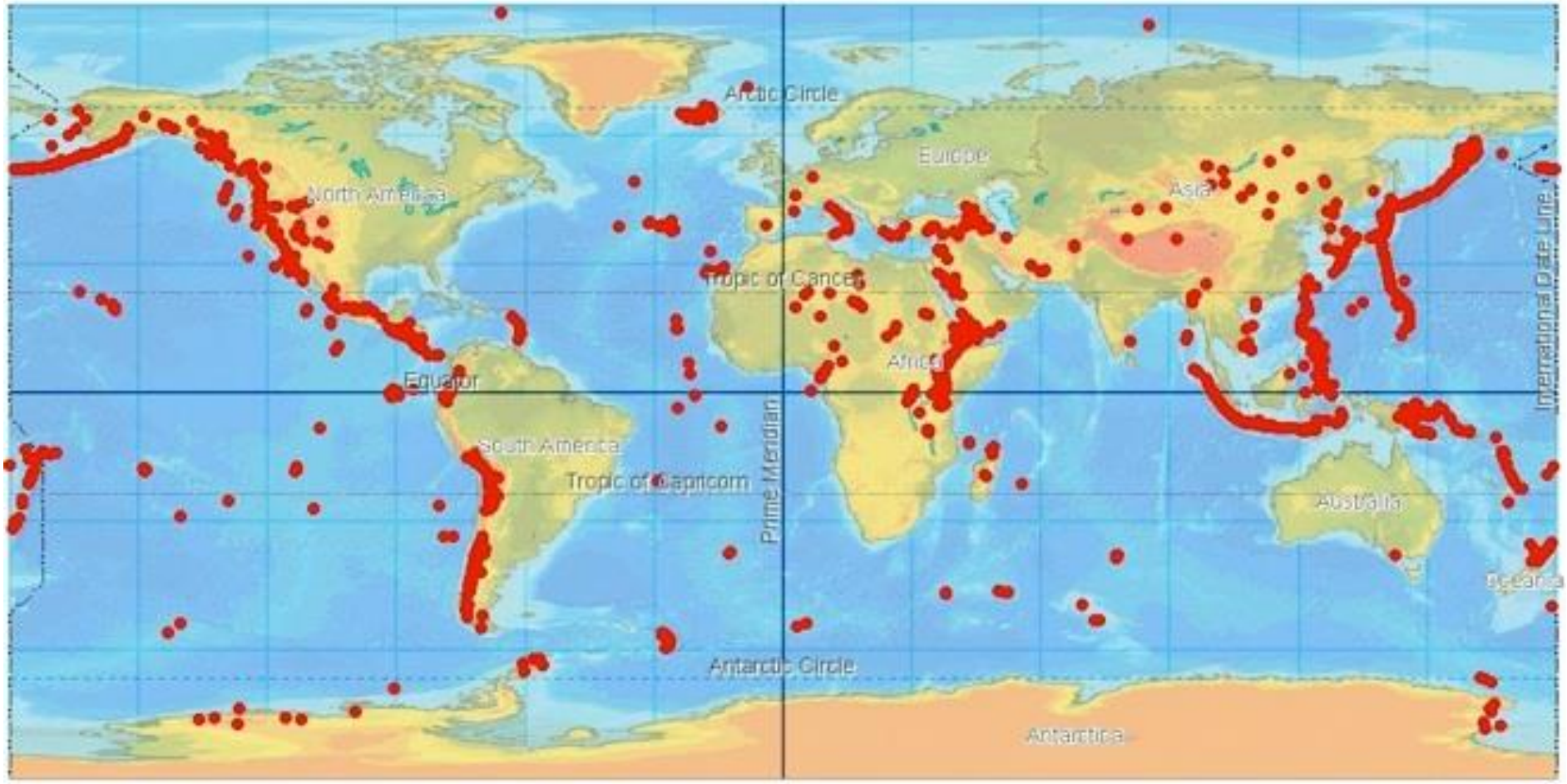
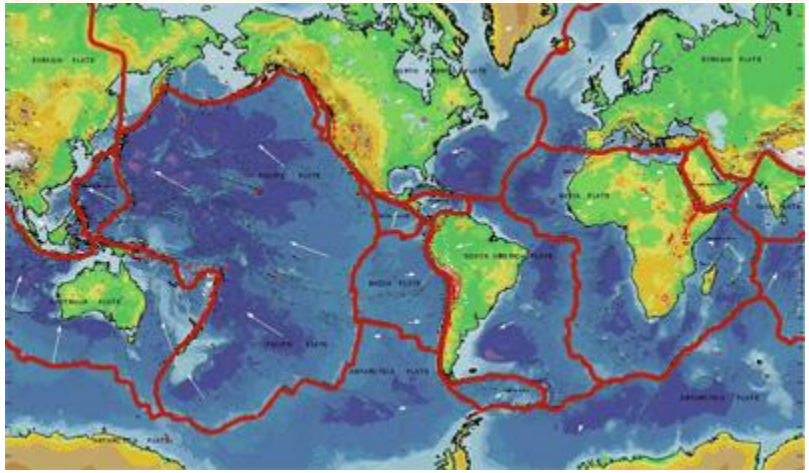
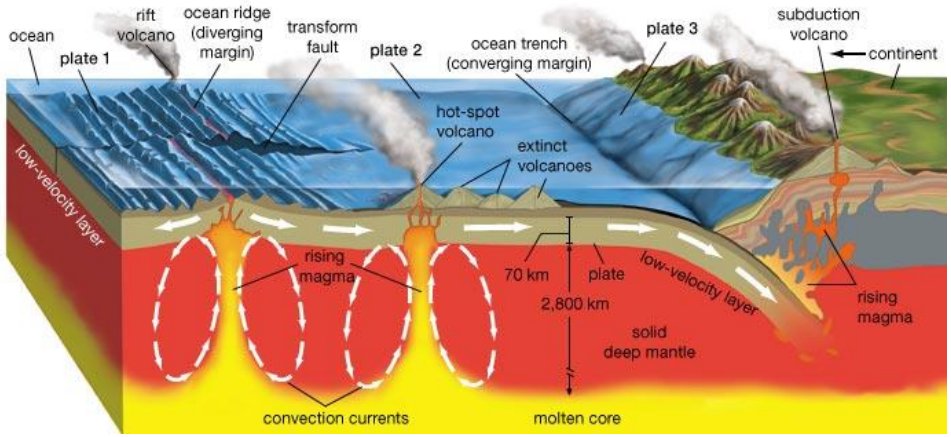
Geophysical studies in active volcanoes
Estudios geofísicos en volcanes activos

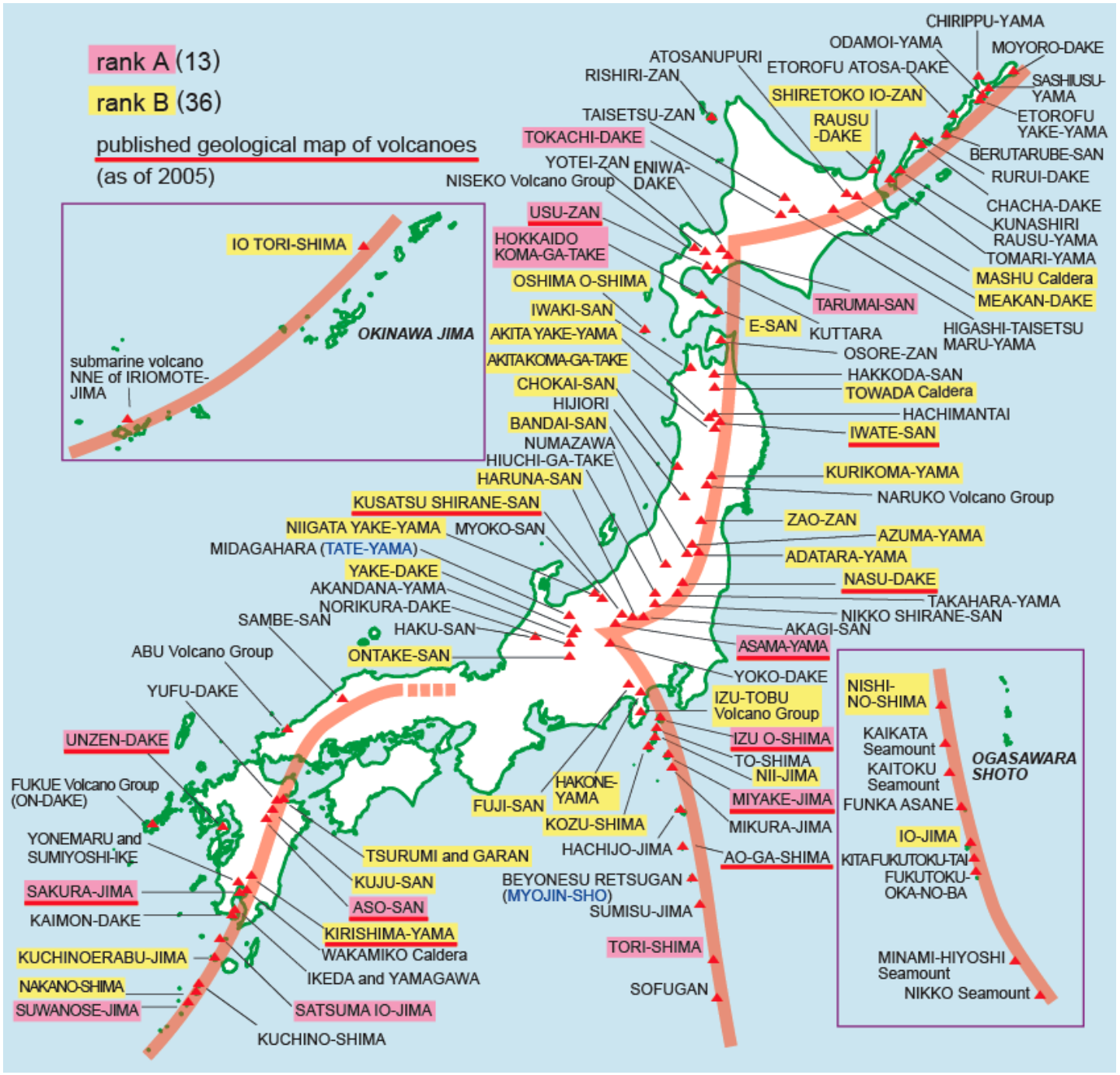
J Urrutia Fucugauchi
Academia Mexicana de Ciencias

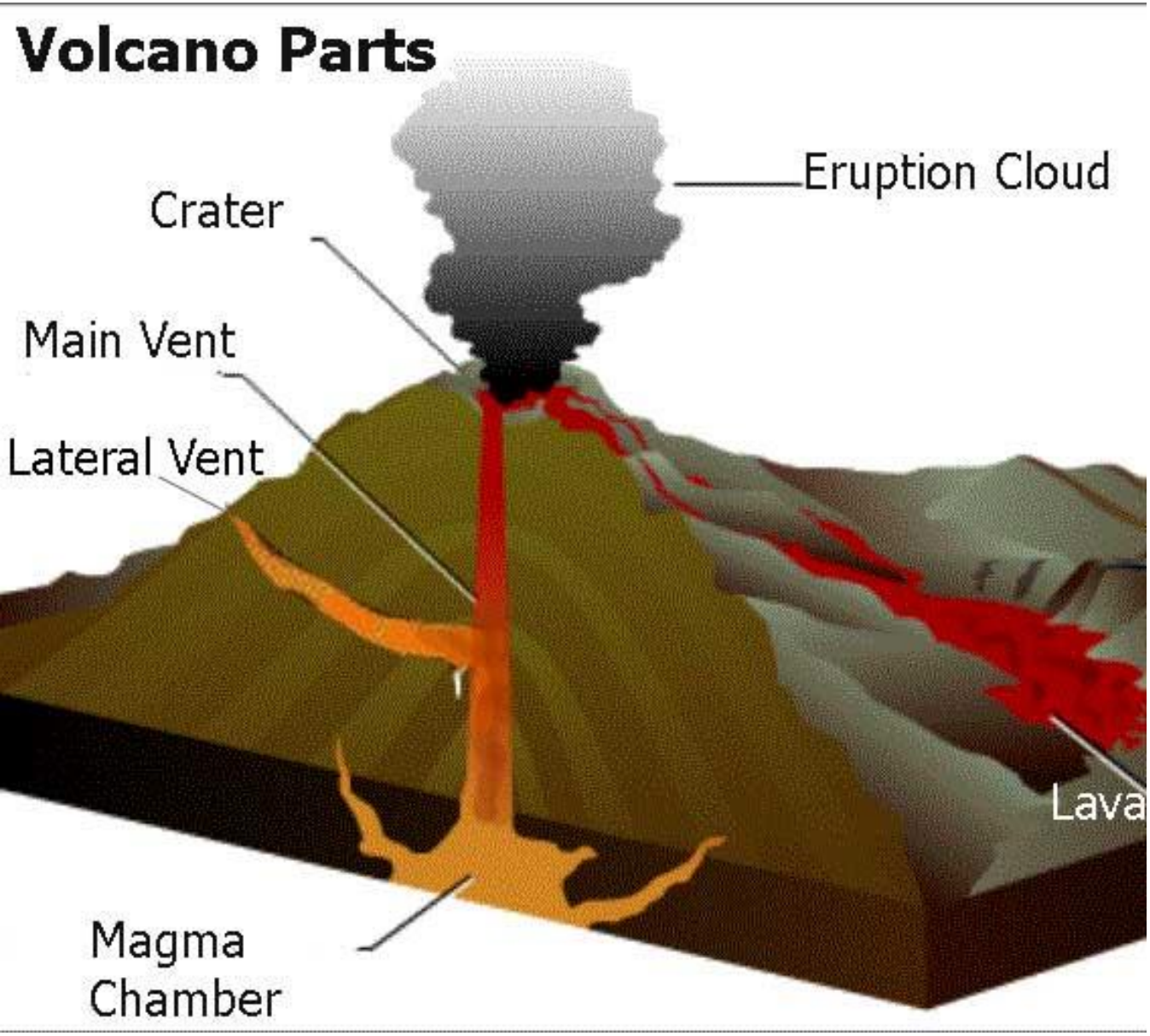
GIFT Workshop Merida 2016


Arctic Circle
Europe
North America
Asia
Tropic of Cancer
Africa
Equator
South America
Tropic of Capricorn
Prime Meridian
International Date Line
Australia
Oceania
Antarctic Circle
Antarctica



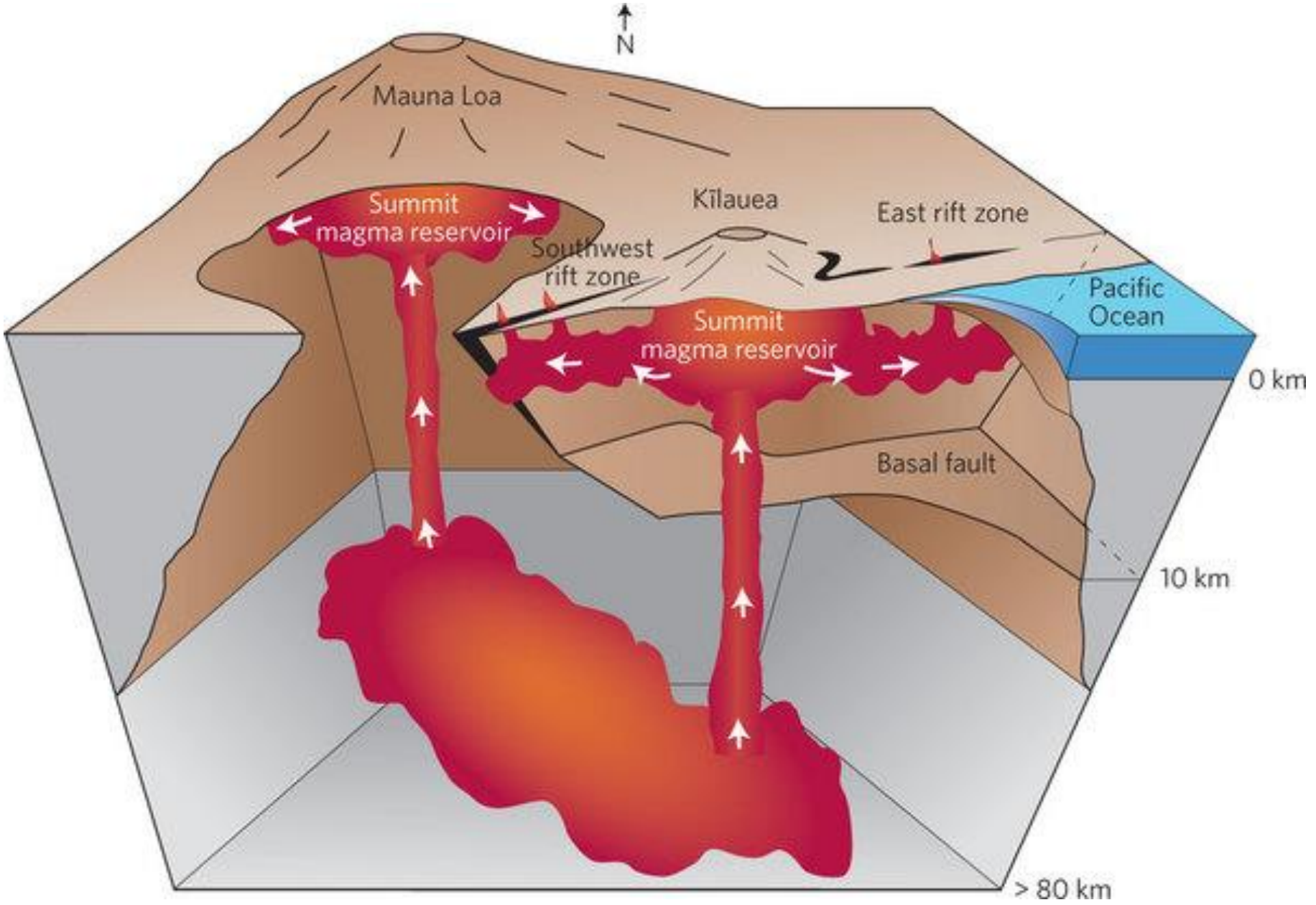

ocean
rift volcano
ocean ridge (diverging margin)
transform fault
plate 1
plate 2
ocean trench (converging margin)
plate 3
subduction volcano
continent
hot-spot volcano
extinct volcanoes
low-velocity layer
rising magma
70 km
plate
low-velocity layer
rising magma
2,800 km
solid deep mantle
convection currents
molten core


rank A (13)
rank B (36)
published geological map of volcanoes
(as of 2005)
IO TORI-SHIMA
OKINAWA JIMA
submarine volcano NNE of IRIOMOTE-JIMA
CHIRIPPU-YAMA
ODAMOI-YAMA
MOYORO-DAKE
ATOSANUPURI
ETOROFU ATOSA-DAKE
SASHIUSU-YAMA
RISHIRI-ZAN
SHIRETOKO IO-ZAN
ETOROFU YAKE-YAMA
TAISETSU-ZAN
RAUSU -DAKE
BERUTARUBE-SAN
TOKACHI-DAKE
YOTEI-ZAN
ENIWA-DAKE
RURUI-DAKE
NISEKO Volcano Group
CHACHA-DAKE
KUNASHIRI
USU-ZAN
RAUSU-YAMA
HOKKAIDO KOMA-GA-TAKE
TOMARI-YAMA
MASHU Caldera
OSHIMA O-SHIMA
TARUMAI-SAN
MEAKAN-DAKE
IWAKI-SAN
E-SAN
KUTTARA
HIGASHI-TAISETSU MARU-YAMA
AKITA YAKE-YAMA
OSORE-ZAN
AKITAKOMA-GA-TAKE
HAKKODA-SAN
CHOKAI-SAN
TOWADA Caldera
HIJIORI
HACHIMANTAI
BANDAI-SAN
IWATE-SAN
NUMAZAWA
HIUCHI-GA-TAKE
KURIKOMA-YAMA
HARUNA-SAN
NARUKO Volcano Group
KUSATSU SHIRANE-SAN
ZAO-ZAN
NIIGATA YAKE-YAMA
MYOKO-SAN
AZUMA-YAMA
MIDAGAHARA (TATE-YAMA)
ADATARA-YAMA
YAKE-DAKE
NASU-DAKE
AKANDANA-YAMA
TAKAHARA-YAMA
NORIKURA-DAKE
NIKKO SHIRANE-SAN
SAMBE-SAN
HAKU-SAN
AKAGI-SAN
ABU Volcano Group
ONTAKE-SAN
ASAMA-YAMA
YOKO-DAKE
YUFU-DAKE
IZU-TOBU Volcano Group
UNZEN-DAKE
IZU O-SHIMA
TO-SHIMA
FUKUE Volcano Group (ON-DAKE)
NII-JIMA
HAKONE-YAMA
FUJI-SAN
MIYAKE-JIMA
KOZU-SHIMA
MIKURA-JIMA
YONEMARU and SUMIYOSHI-IKE
HACHIJO-JIMA
AO-GA-SHIMA
TSURUMI and GARAN
KUJU-SAN
BEYONESU RETSUGAN (MYOJIN-SHO)
SAKURA-JIMA
ASO-SAN
SUMISU-JIMA
KAIMON-DAKE
KIRISHIMA-YAMA
TORI-SHIMA
KUCHINOERABU-JIMA
WAKAMIKO Caldera
SOFUGAN
IKEDA and YAMAGAWA
NAKANO-SHIMA
SUWANOSE-JIMA
SATSUMA IO-JIMA
KUCHINO-SHIMA
NISHI-NO-SHIMA
KAIKATA Seamount
OGASAWARA SHOTO
KAITOKU Seamount
FUNKA ASANE
IO-JIMA
KITAFUKUTOKU-TAI
FUKUTOKU-OKA-NO-BA
MINAMI-HIYOSHI Seamount
NIKKO Seamount

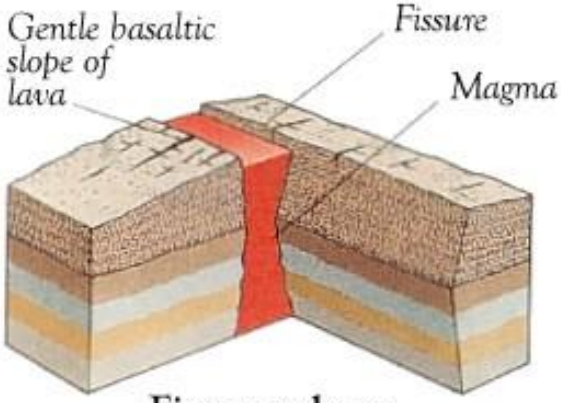


Geophysics

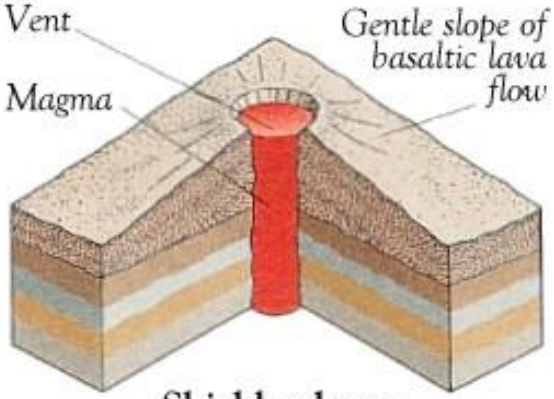
Internal structure
Volcanic conduits
Magma processes
Eruptive processes
Volcano instability
Alteration
Volcano collapse
Debris avalanches


N
Mauna Loa
Kīlauea
East rift zone
Summit
magma reservoir
Southwest
rift zone
Pacific
Ocean
Summit
magma reservoir
0 km
Basal fault
10 km
> 80 km

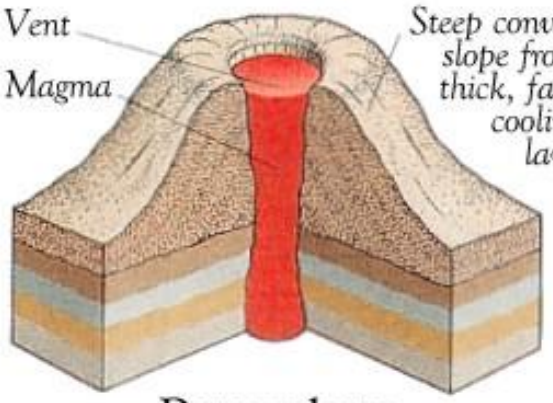
TYPES OF VOLCANO



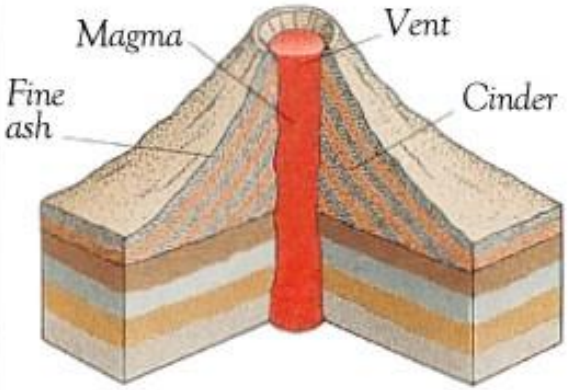
Fissure volcano



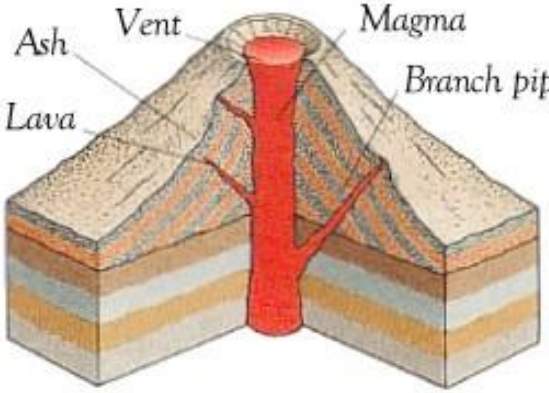
Shield volcano



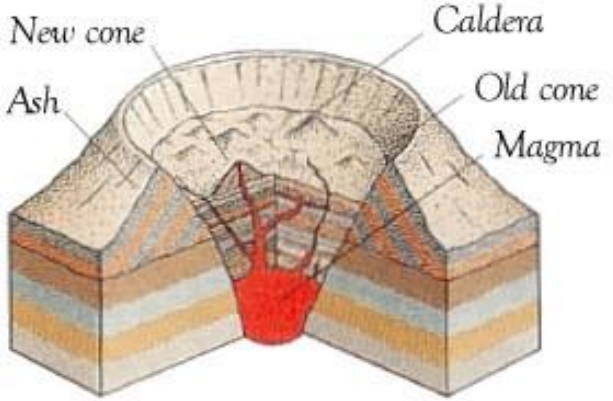
Dome volcano



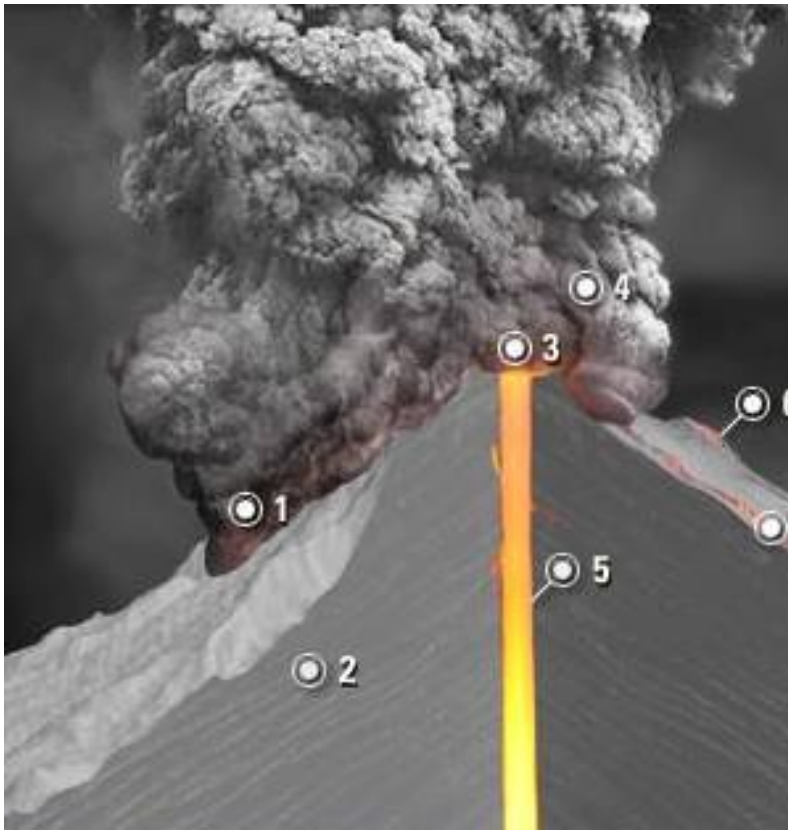
Ash-cinder volcano

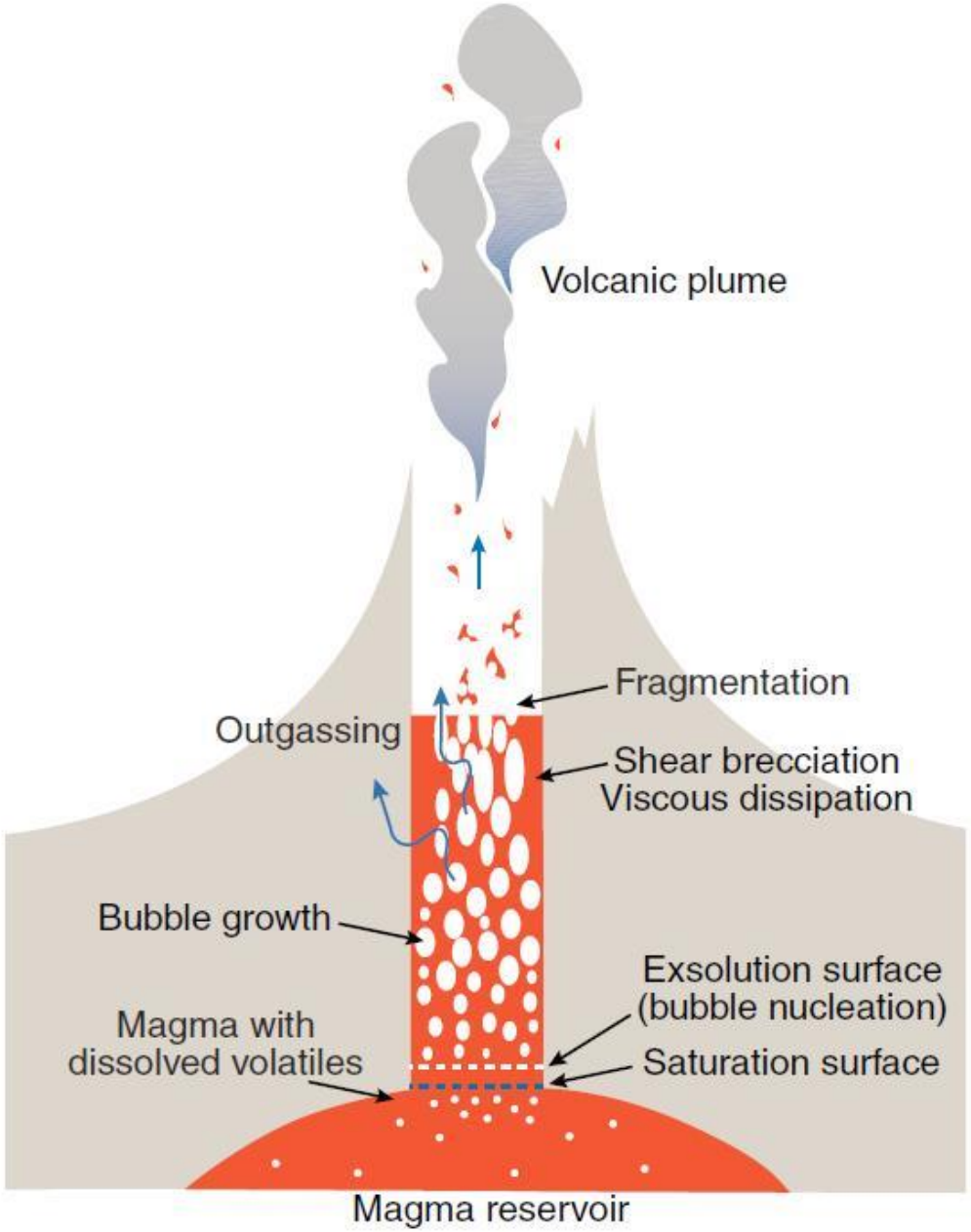


Composite volcano



Caldera volcano

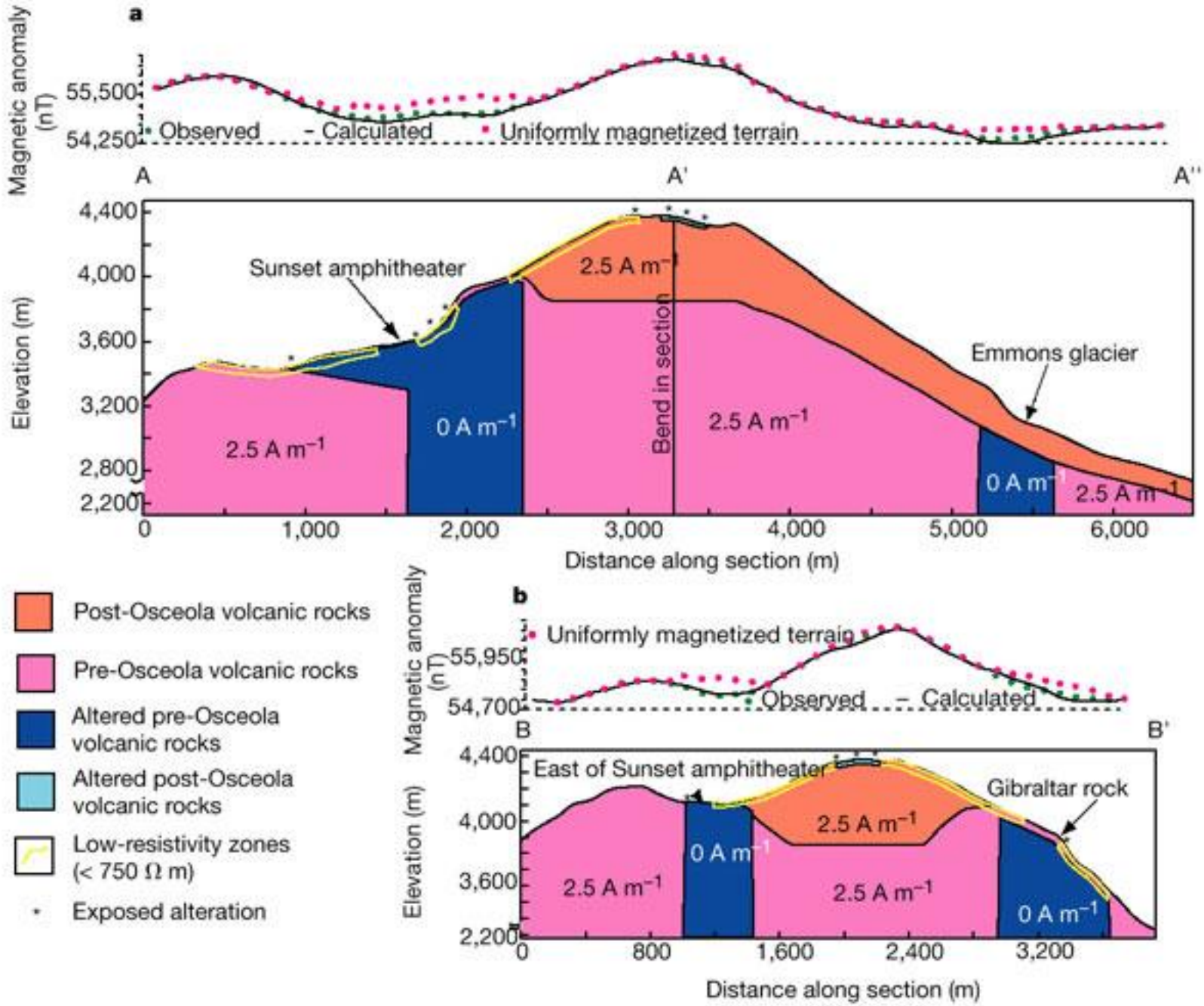

1
2
3
4
5


Volcanic plume
Fragmentation
Outgassing
Shear brecciation
Viscous dissipation
Bubble growth
Exsolution surface
(bubble nucleation)
Magma with
dissolved volatiles
Saturation surface
Magma reservoir

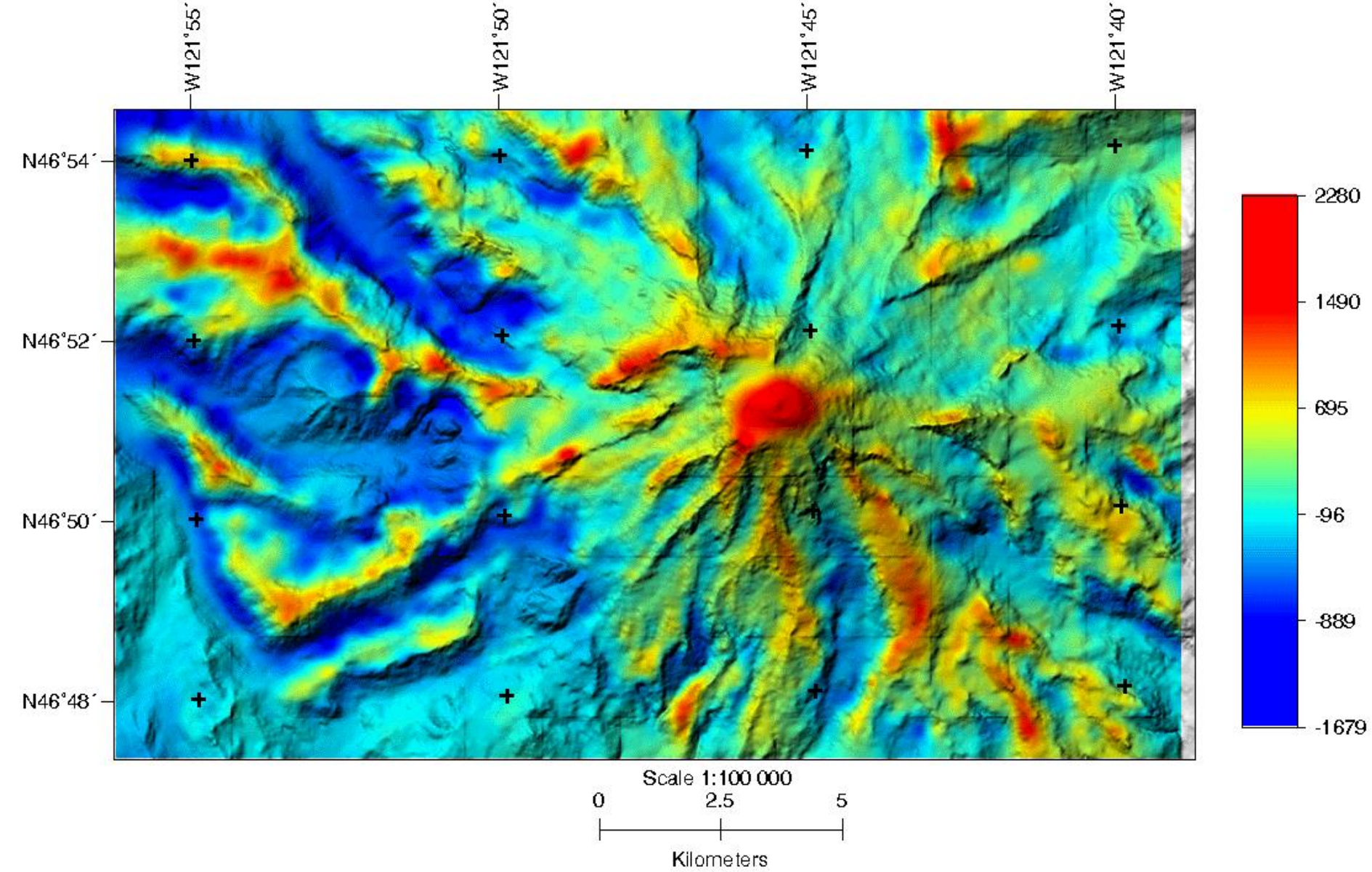
Aerogeophysics

Features

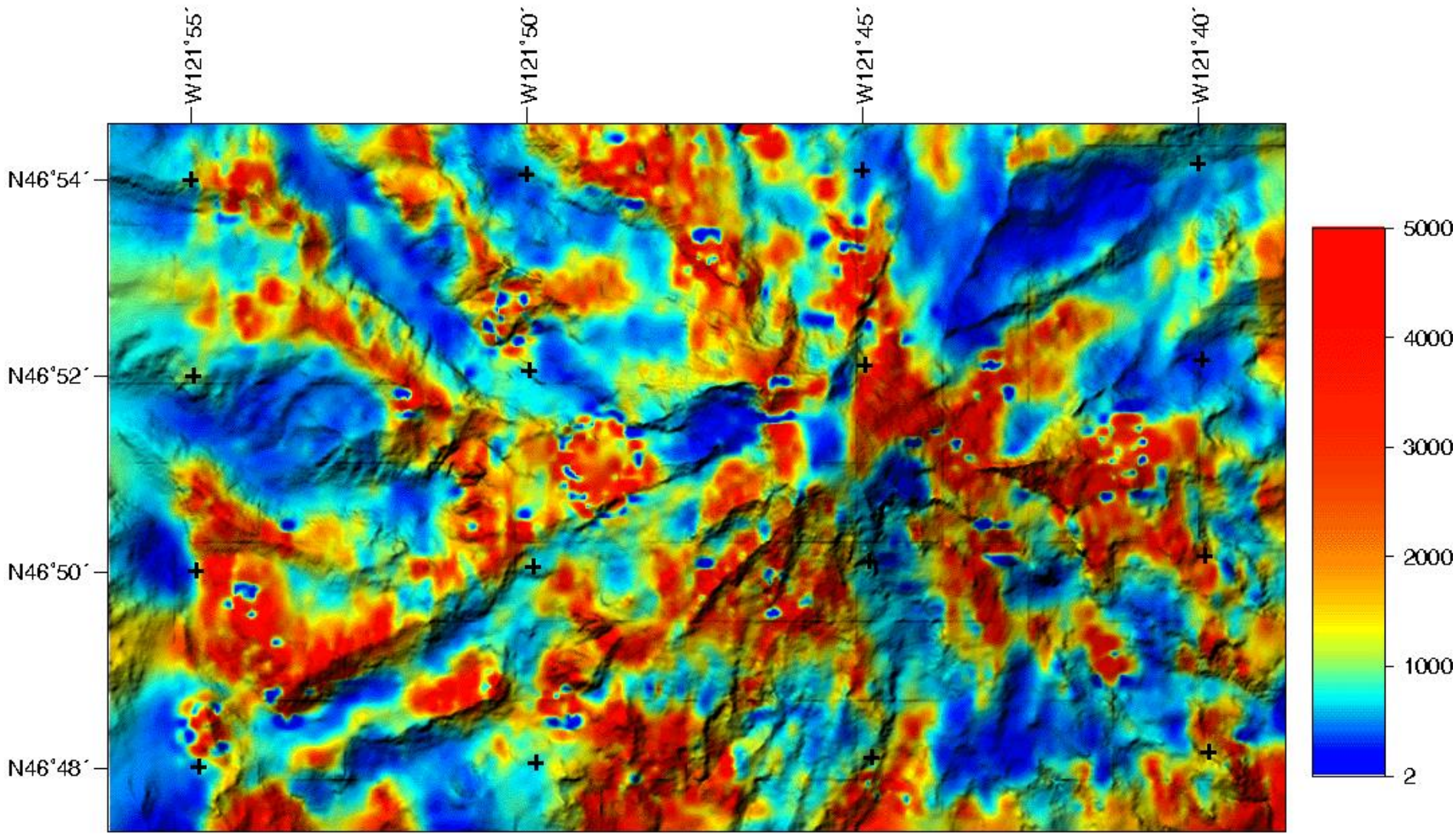
- Operating speed less than 250 km/h
- Twin engine (if not helicopter)
- High-wings for better visibility
- Long (> 6 hours) endurance with full operational load (250kg plus operator)
- Short take-off & landing performance.

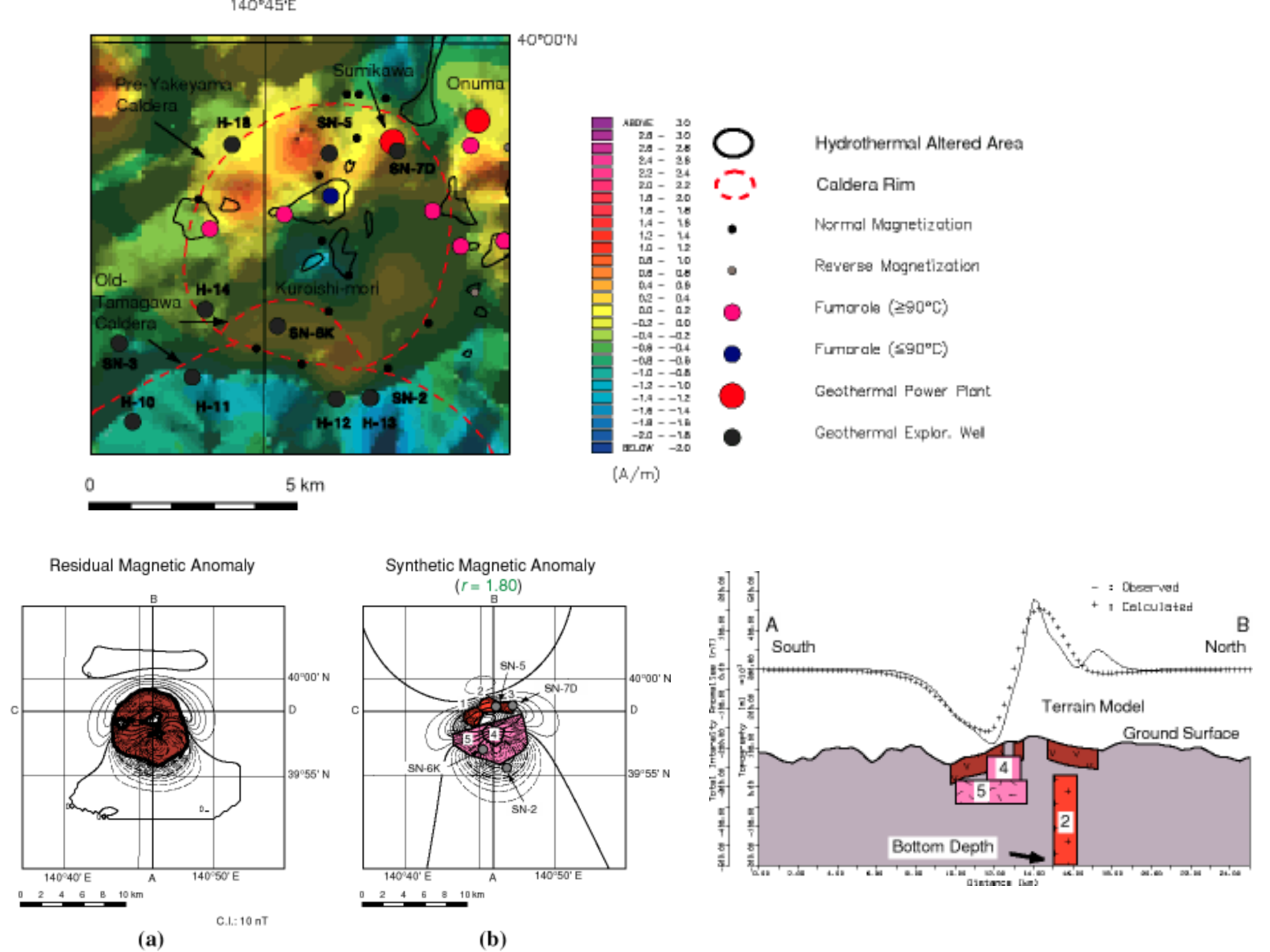

a
Magnetic anomaly (nT)
55,500
54,250
Observed
Calculated
Uniformly magnetized terrain
A
A'
A''
Elevation (m)
4,400
4,000
3,600
3,200
2,800
2,200
Sunset amphitheater
2.5 A m−1
0 A m−1
Bend in section
Emmons glacier
0
1,000
2,000
3,000
4,000
5,000
6,000
Distance along section (m)
Post-Osceola volcanic rocks
Pre-Osceola volcanic rocks
Altered pre-Osceola volcanic rocks
Altered post-Osceola volcanic rocks
Low-resistivity zones (< 750 Ω m)
Exposed alteration
b
Magnetic anomaly (nT)
55,950
54,700
Uniformly magnetized terrain
Observed
Calculated
B
B'
Elevation (m)
4,400
4,000
3,600
2,200
East of Sunset amphitheater
Gibraltar rock
2.5 A m−1
0 A m−1
0
800
1,600
2,400
3,200
Distance along section (m)

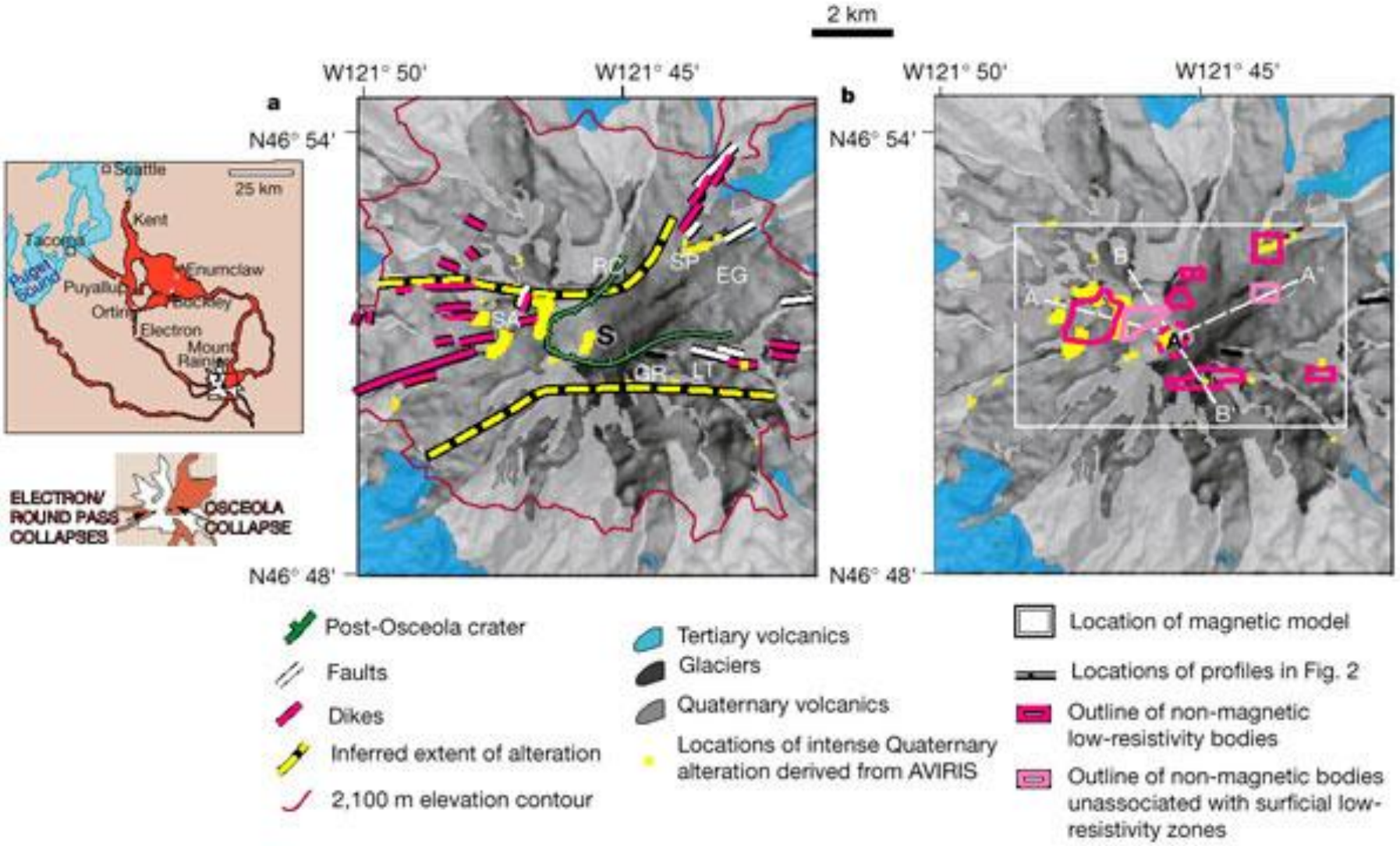
Mt. Rainier Aeromagnetic (colors) and Topographic (shading) Data

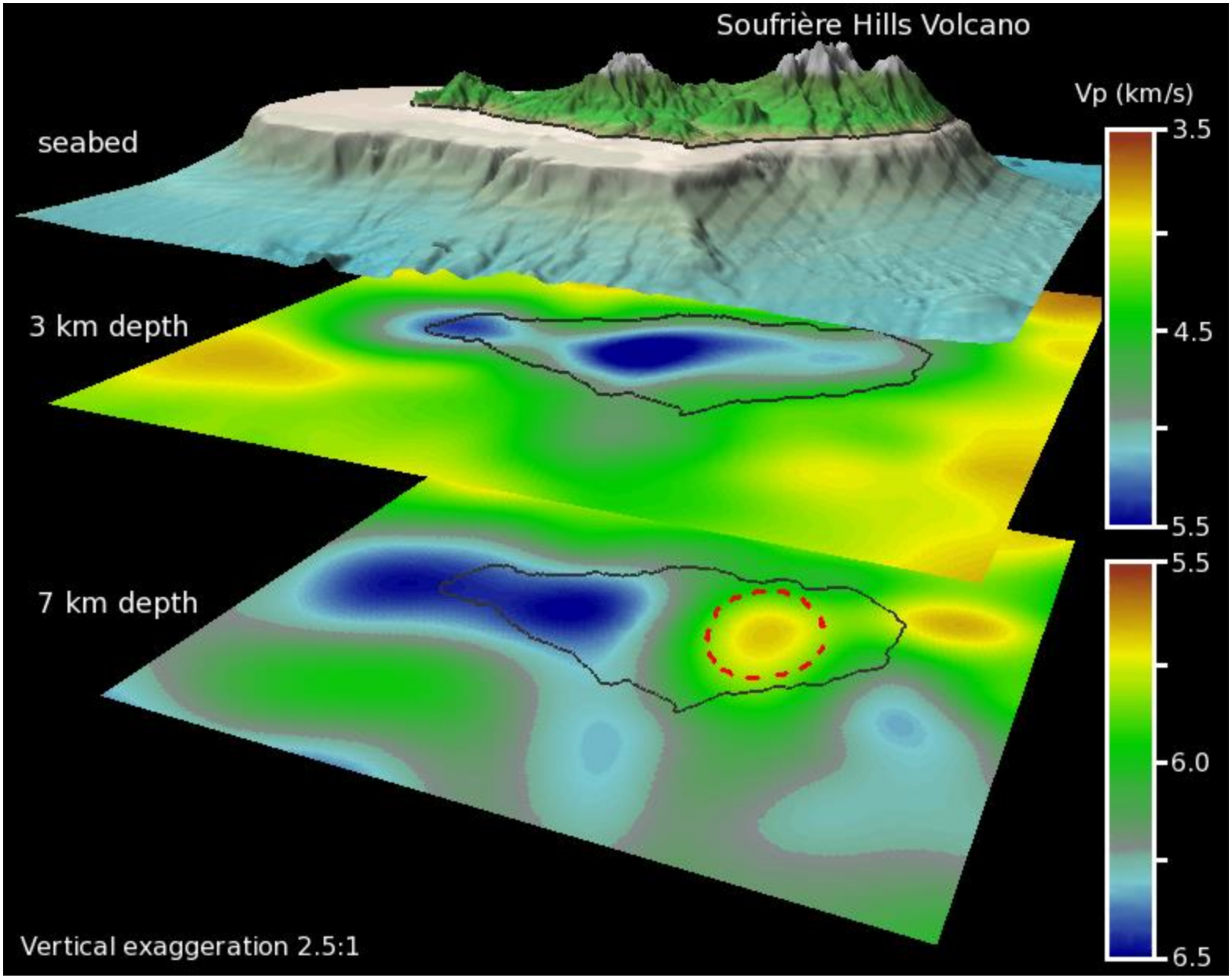


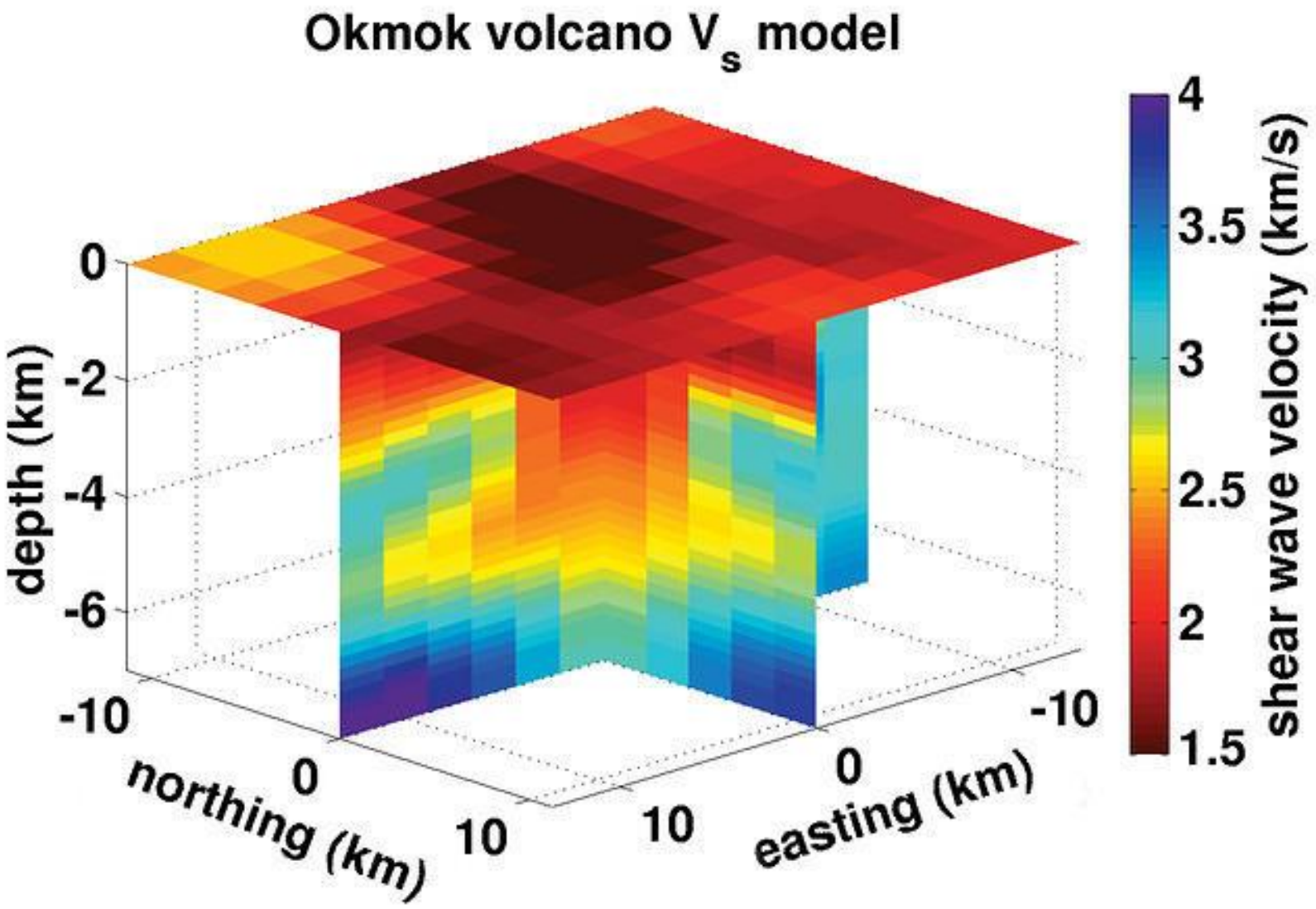
Mt. Rainier 837 Hz Resistivity (colors) and Topographic Data (shading)

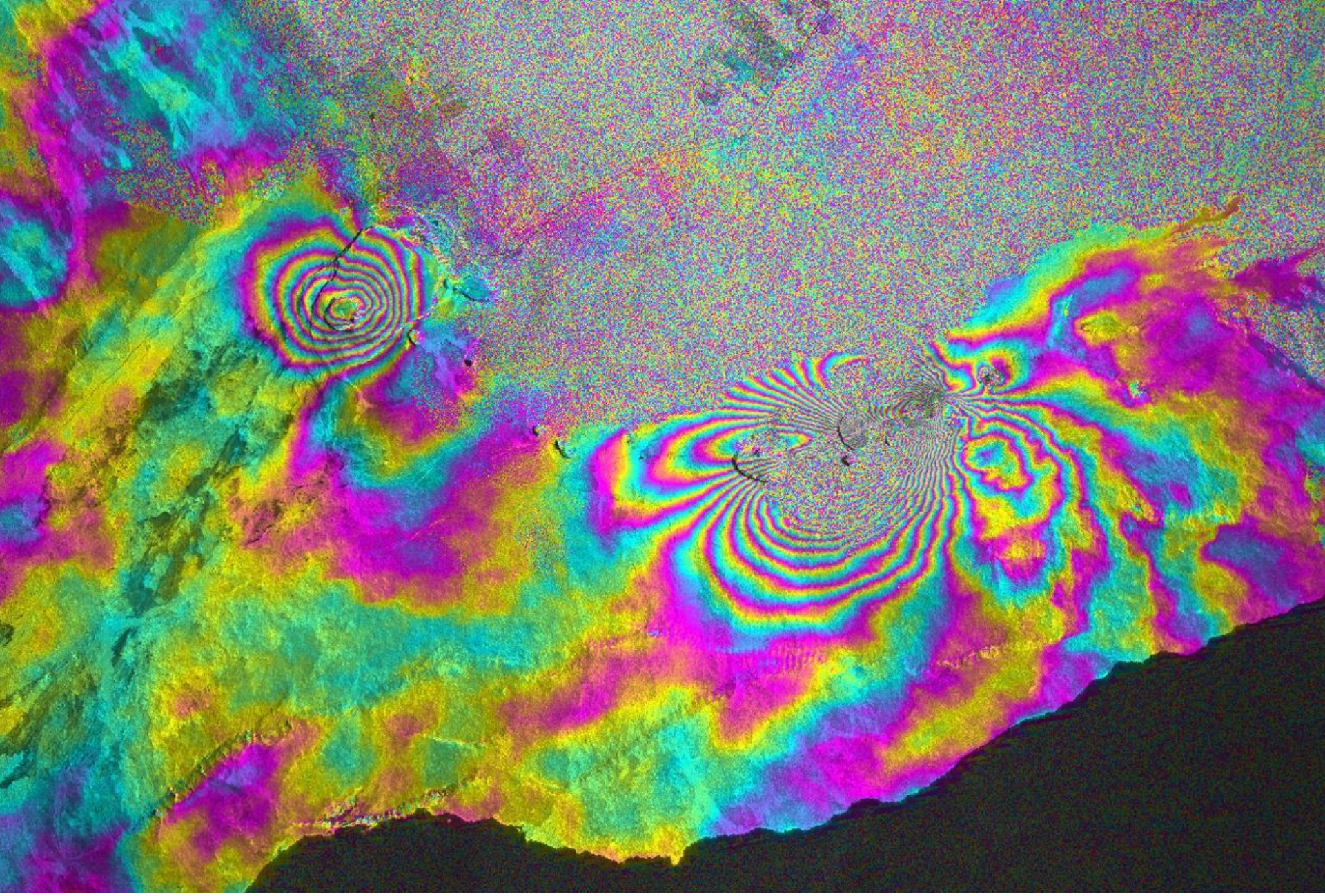



140°45'E
40°00'N
Pre-Yakeyama Caldera
Sumikawa
Onuma
H-18
SN-5
SN-7D
Old-Tamagawa Caldera
H-14
Kuroishi-mori
SN-8K
SN-3
H-10
H-11
H-12
H-13
SN-2
0
5 km
ABOVE 3.0
2.8 – 3.0
2.6 – 2.8
2.4 – 2.6
2.2 – 2.4
2.0 – 2.2
1.8 – 2.0
1.6 – 1.8
1.4 – 1.6
1.2 – 1.4
1.0 – 1.2
0.8 – 1.0
0.6 – 0.8
0.4 – 0.6
0.2 – 0.4
0.0 – 0.2
-0.2 – 0.0
-0.4 – -0.2
-0.6 – -0.4
-0.8 – -0.6
-1.0 – -0.8
-1.2 – -1.0
-1.4 – -1.2
-1.6 – -1.4
-1.8 – -1.6
-2.0 – -1.8
BELOW -2.0
(A/m)
Hydrothermal Altered Area
Caldera Rim
Normal Magnetization
Reverse Magnetization
Fumarole (≧90°C)
Fumarole (≦90°C)
Geothermal Power Plant
Geothermal Explor. Well
Residual Magnetic Anomaly
B
C
D
A
40°00' N
39°55' N
140°40' E
140°50' E
0 2 4 6 8 10 km
C.I.: 10 nT
(a)
Synthetic Magnetic Anomaly
(r = 1.80)
SN-5
SN-7D
SN-6K
SN-2
1
2
3
4
5
(b)
– : Observed
+ : Calculated
A
South
B
North
Terrain Model
Ground Surface
Bottom Depth
Distance (km)


2 km
W121° 50'
W121° 45'
a
b
N46° 54'
N46° 48'
Seattle
25 km
Kent
Tacoma
Puget Sound
Enumclaw
Puyallup
Buckley
Ortin
Electron
Mount Rainier
ELECTRON/ ROUND PASS COLLAPSES
OSCEOLA COLLAPSE
RC
SP
EG
SA
S
QR
LT
A
A'
B
B'
Post-Osceola crater
Faults
Dikes
Inferred extent of alteration
2,100 m elevation contour
Tertiary volcanics
Glaciers
Quaternary volcanics
Locations of intense Quaternary alteration derived from AVIRIS
Location of magnetic model
Locations of profiles in Fig. 2
Outline of non-magnetic low-resistivity bodies
Outline of non-magnetic bodies unassociated with surficial low-resistivity zones

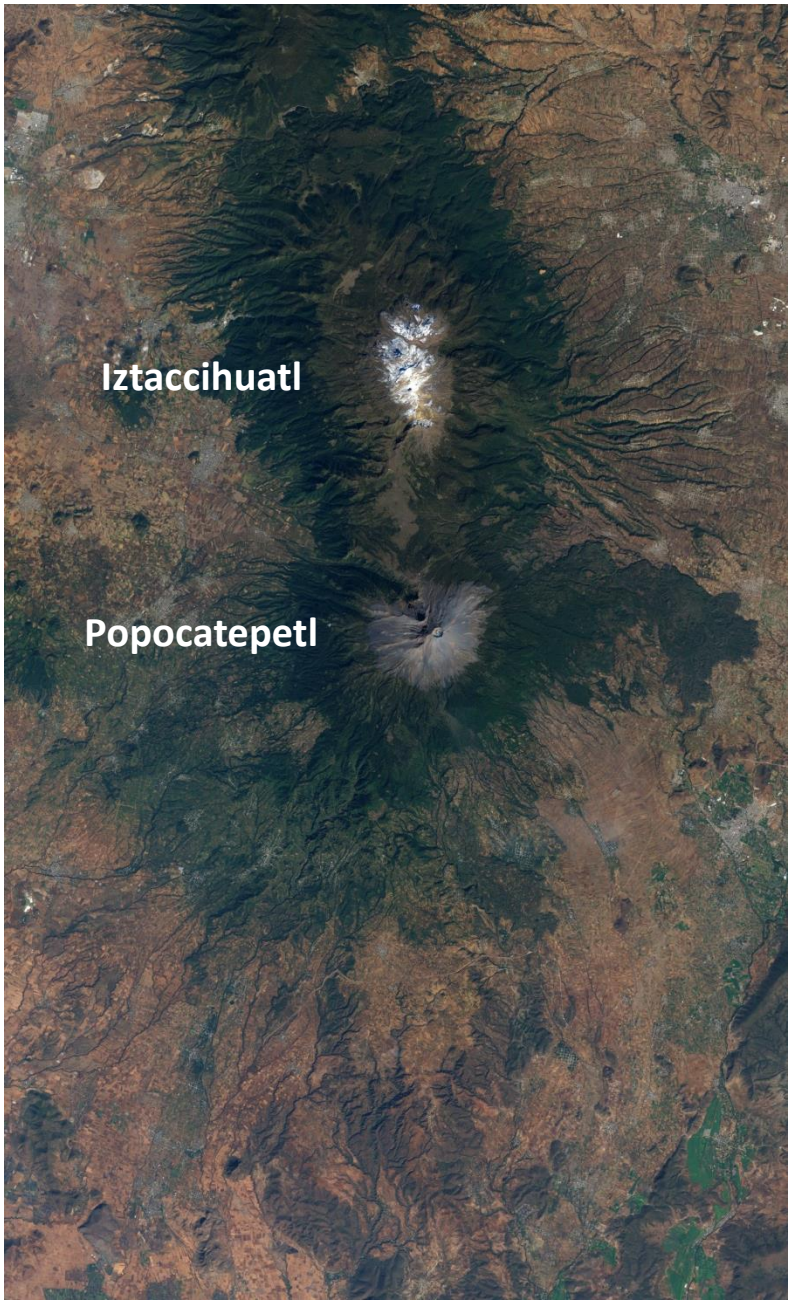

Soufrière Hills Volcano
seabed
3 km depth
7 km depth
Vp (km/s)
3.5
4.5
5.5
5.5
6.0
6.5
Vertical exaggeration 2.5:1


Okmok volcano V_s model
depth (km)
0
-2
-4
-6
-10
0
10
northing (km)
-10
0
10
easting (km)
shear wave velocity (km/s)
4
3.5
3
2.5
2
1.5

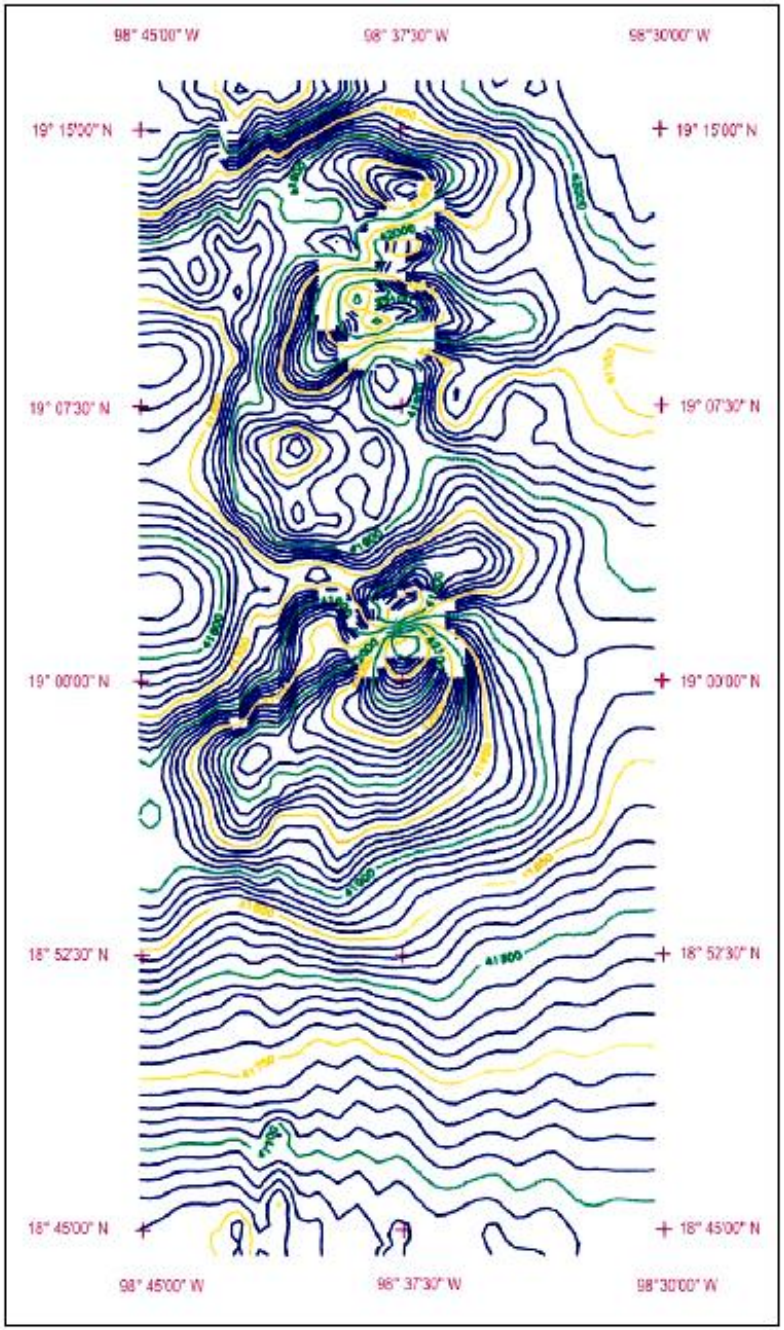


Kilauea volcano InSAR deformation

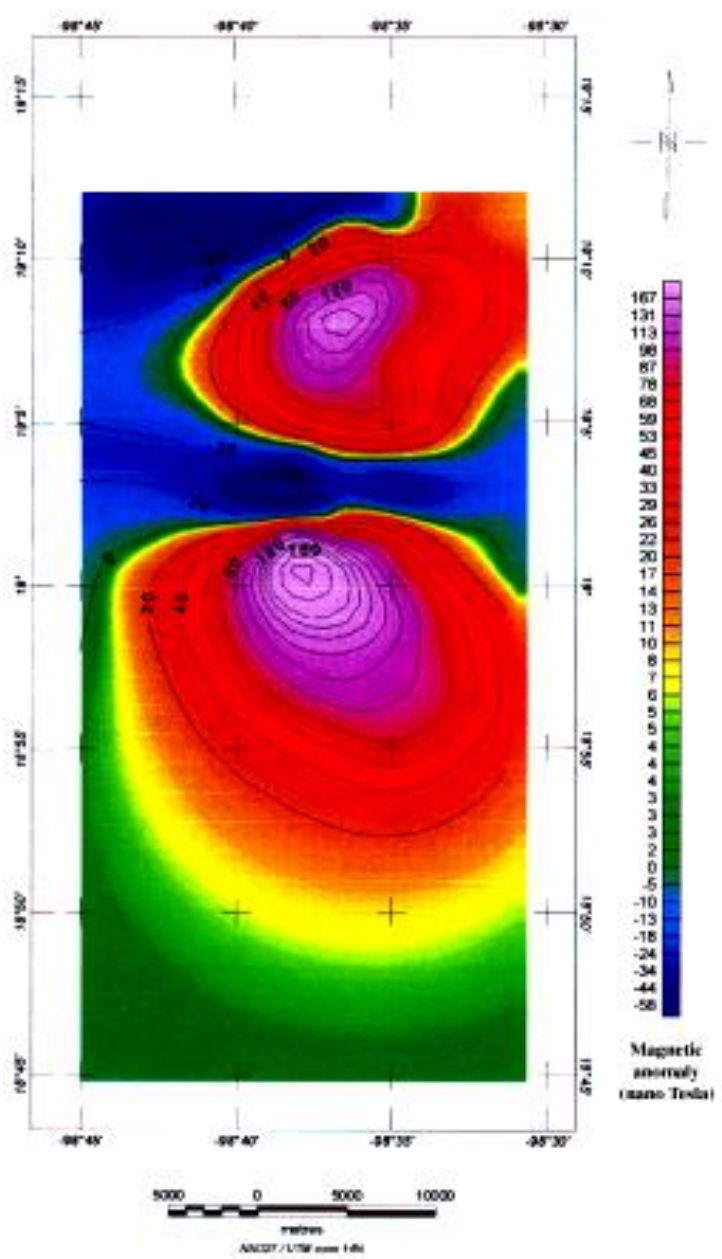
Active volcanoes in Mexico


Iztaccihuatl
Popocatepetl

A)

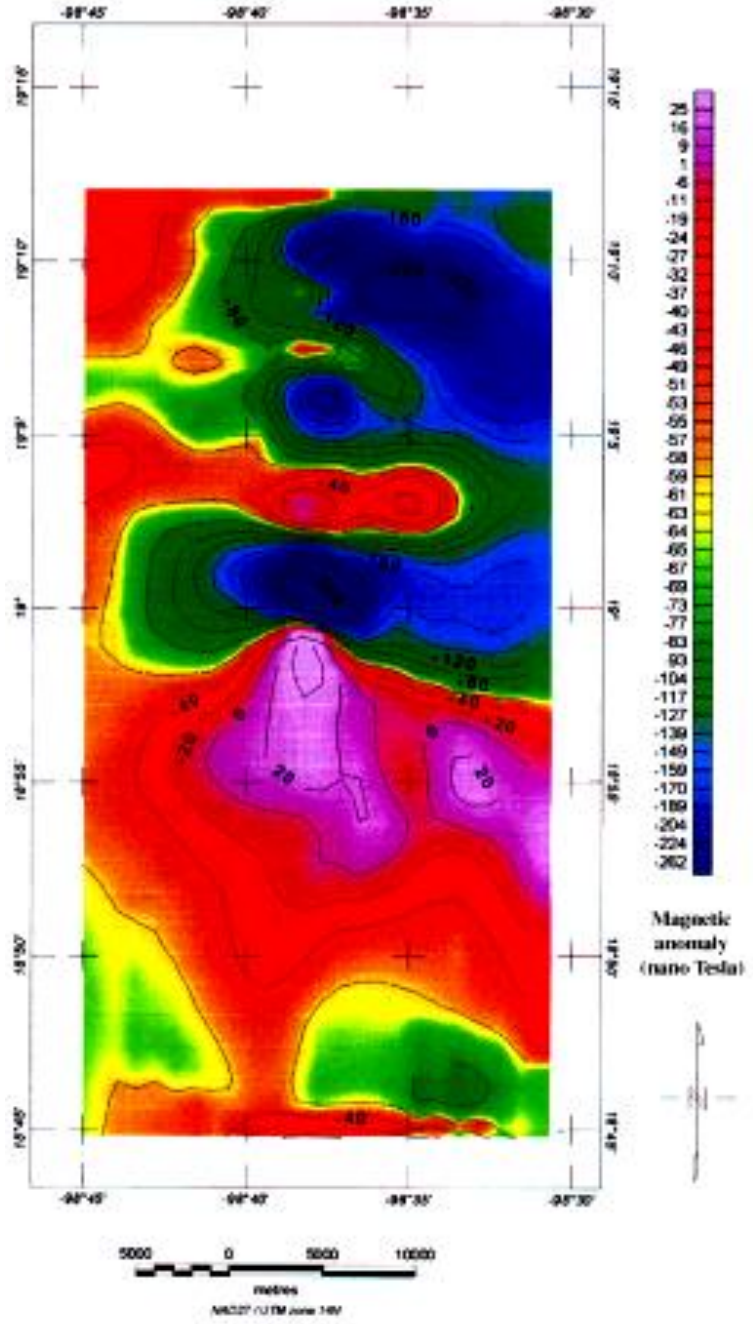

98° 45'00" W
98° 37'30" W
98°30'00" W
19° 15'00" N
19° 07'30" N
19° 00'00" N
18° 52'30" N
18° 45'00" N
41900

B)

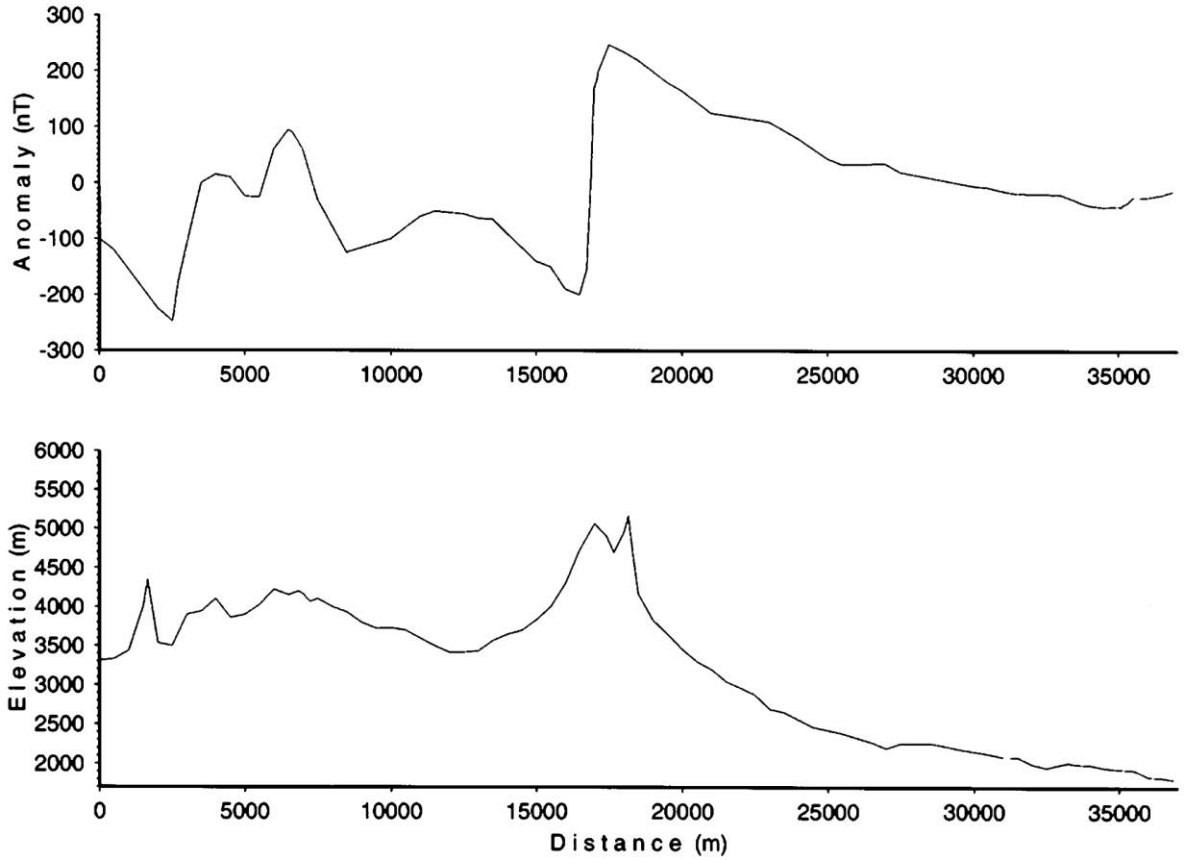


Modeled anomaly from topographic effect

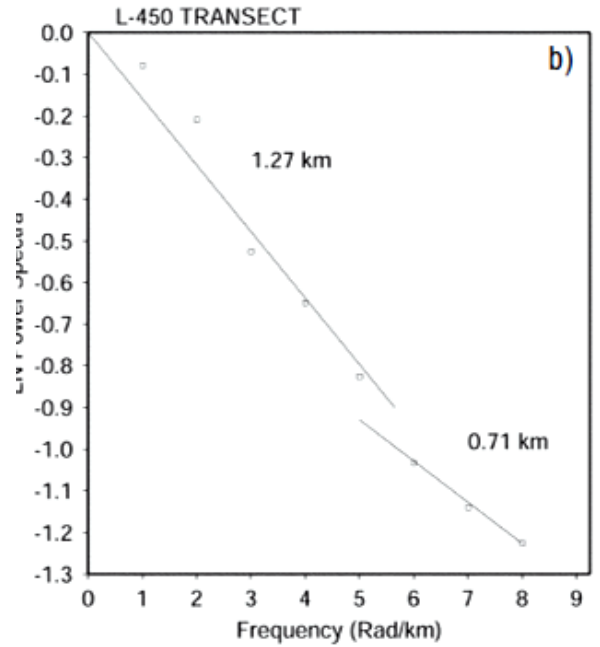
Combination of induced and remanent magnetizations

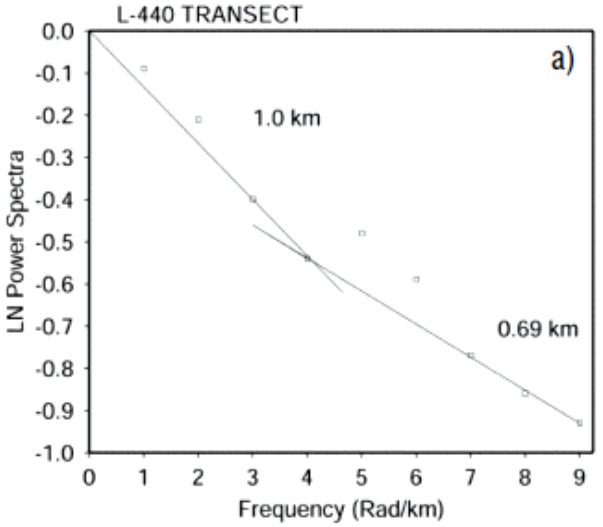


Aeromagnetic anomaly Popocatepetl volcano

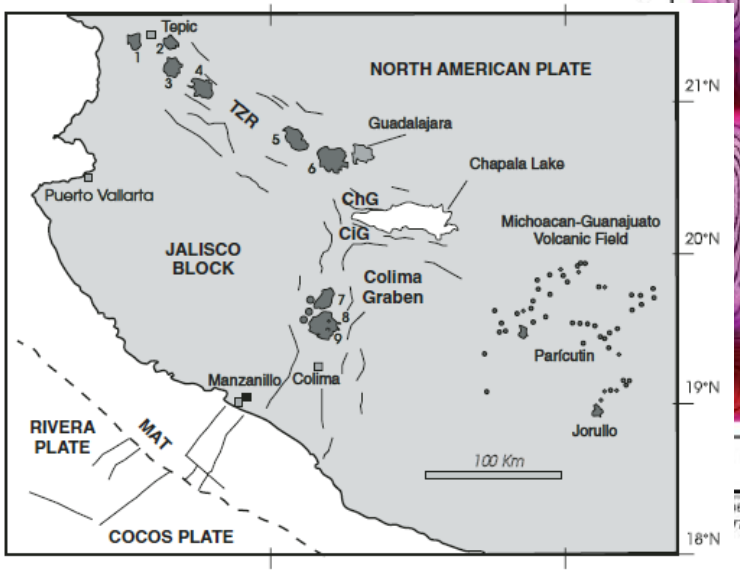


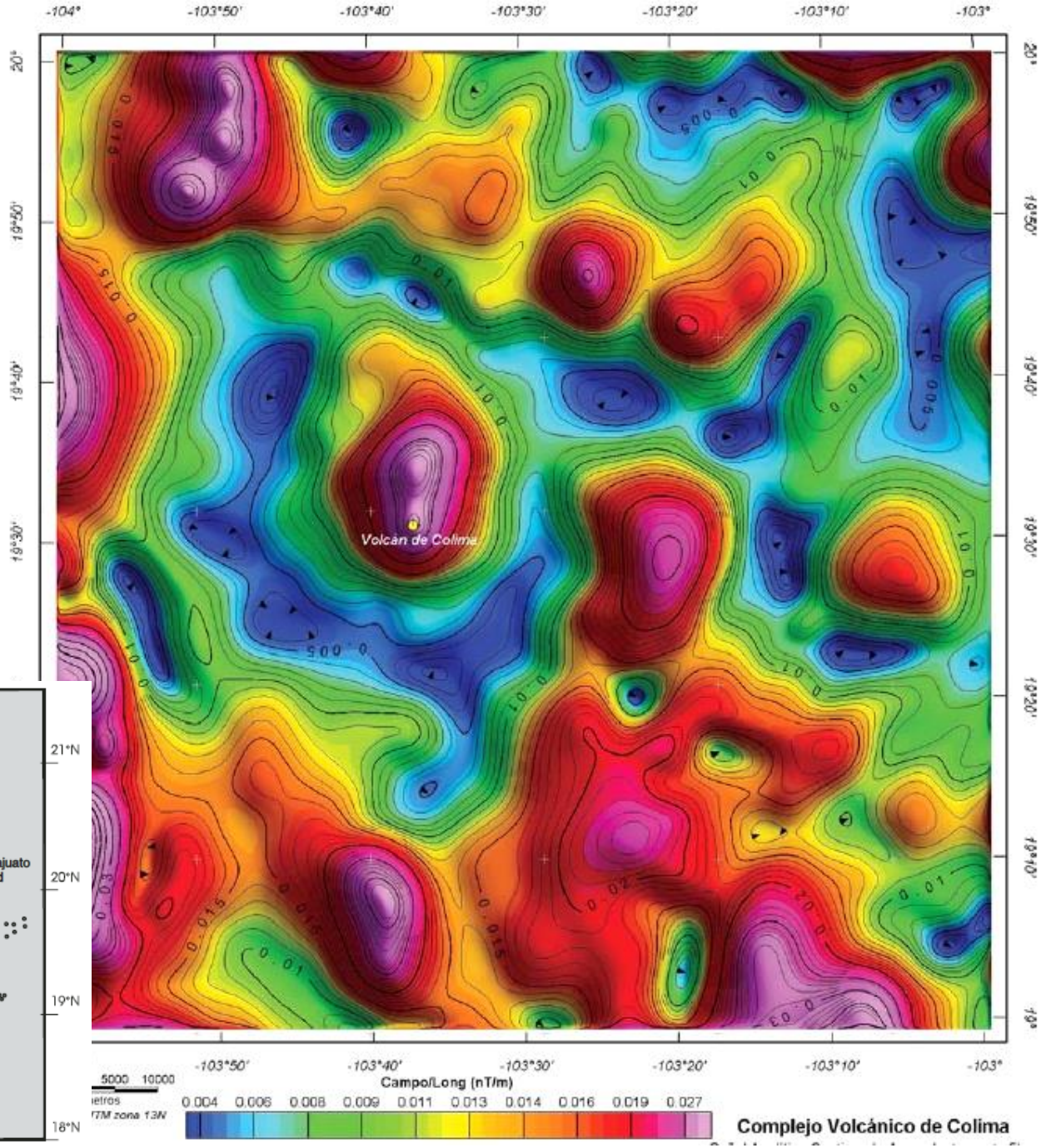
A)

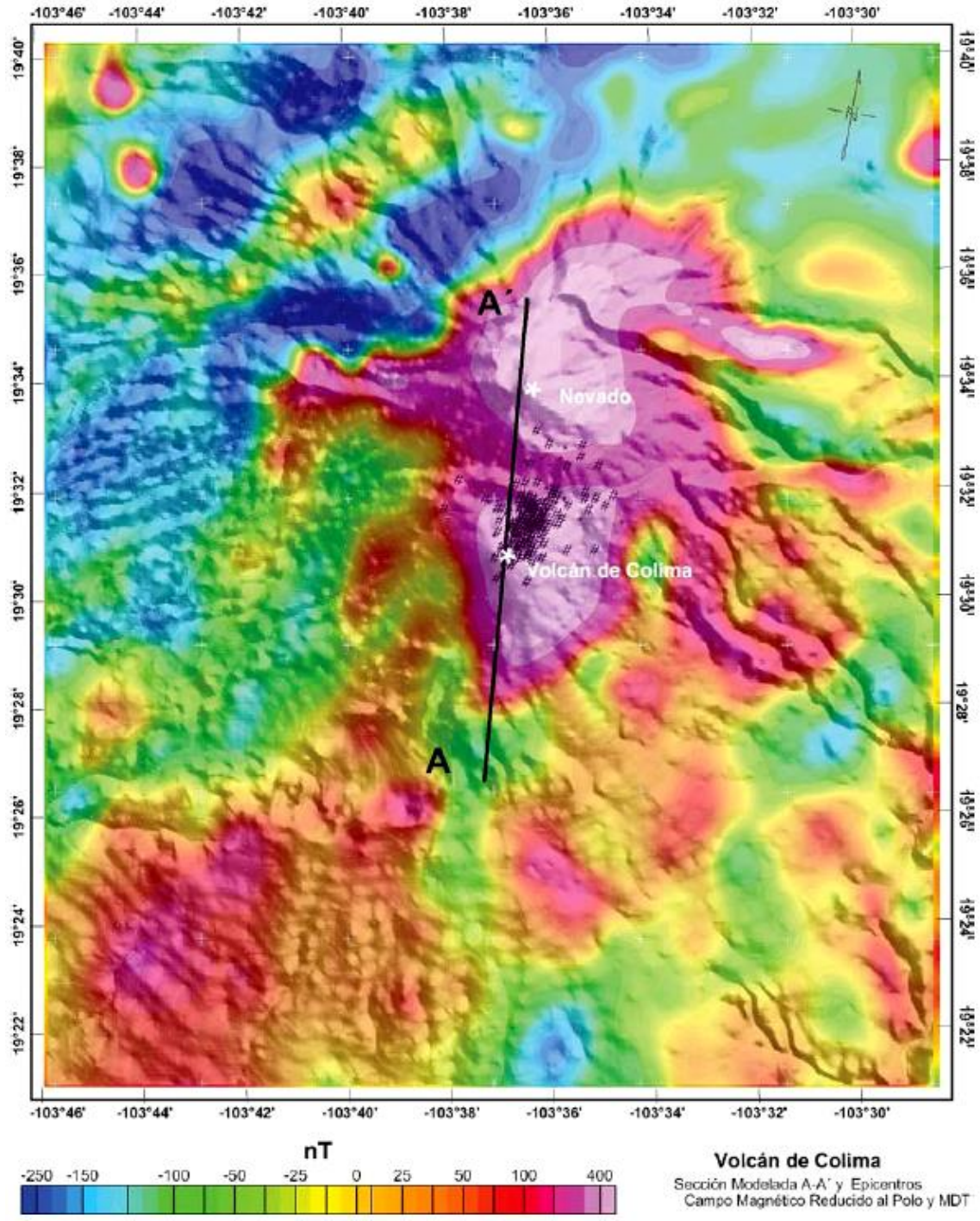




B)

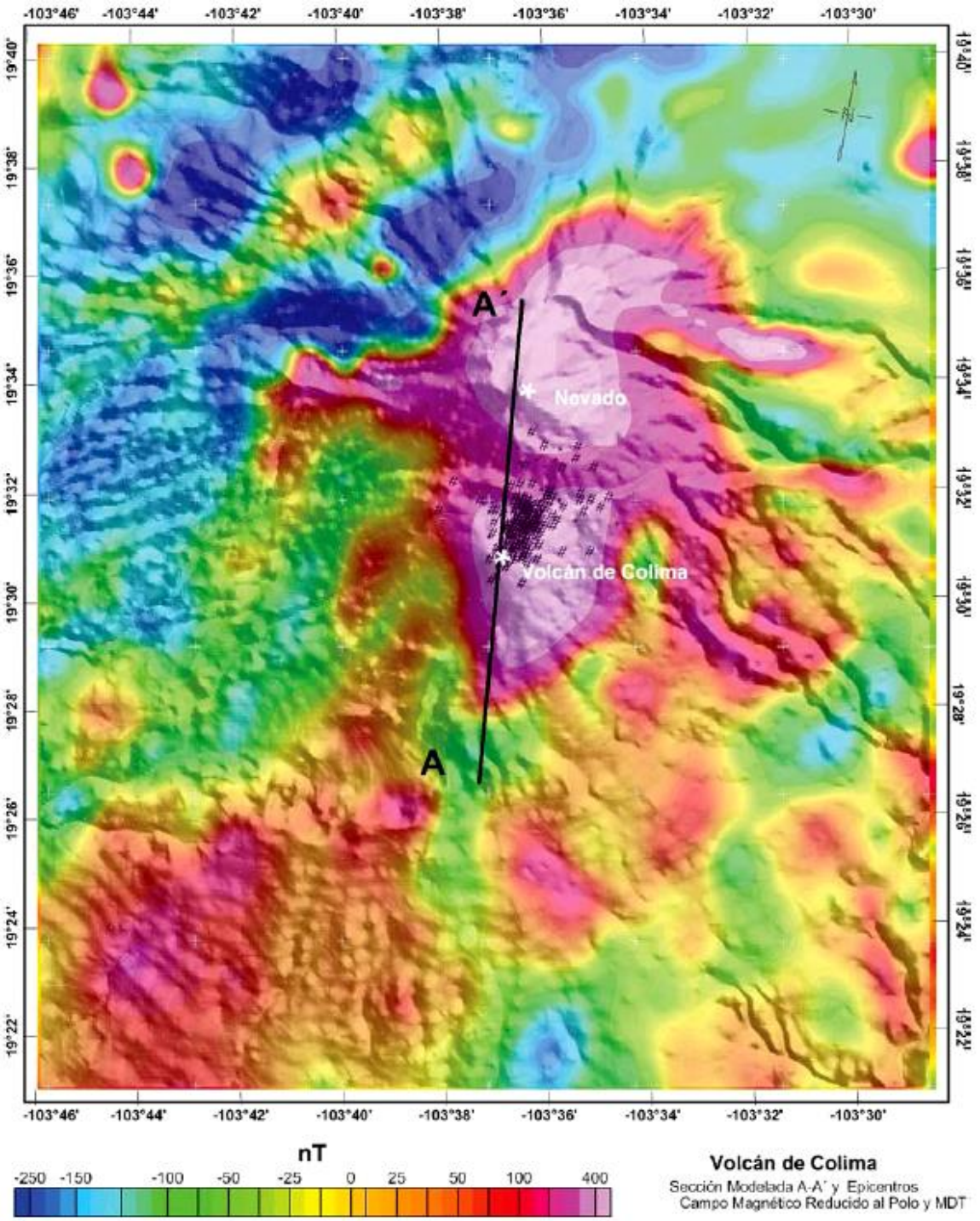

Tepic
NORTH AMERICAN PLATE
TZR
Guadalajara
Chapala Lake
Puerto Vallarta
ChG
CiG
Michoacan-Guanajuato
Volcanic Field
JALISCO
BLOCK
Colima
Graben
Parícutin
Manzanillo
Colima
Jorullo
RIVERA
PLATE
MAT
100 Km
COCOS PLATE
21°N
20°N
19°N
18°N
104°W
102°W


-104°
-103°50'
-103°40'
-103°30'
-103°20'
-103°10'
-103°
20°
19°50'
19°40'
19°30'
19°20'
19°10'
19°
Volcán de Colima
5000 10000
Campo/Long (nT/m)
0.004 0.006 0.008 0.009 0.011 0.013 0.014 0.016 0.019 0.027
Complejo Volcánico de Colima

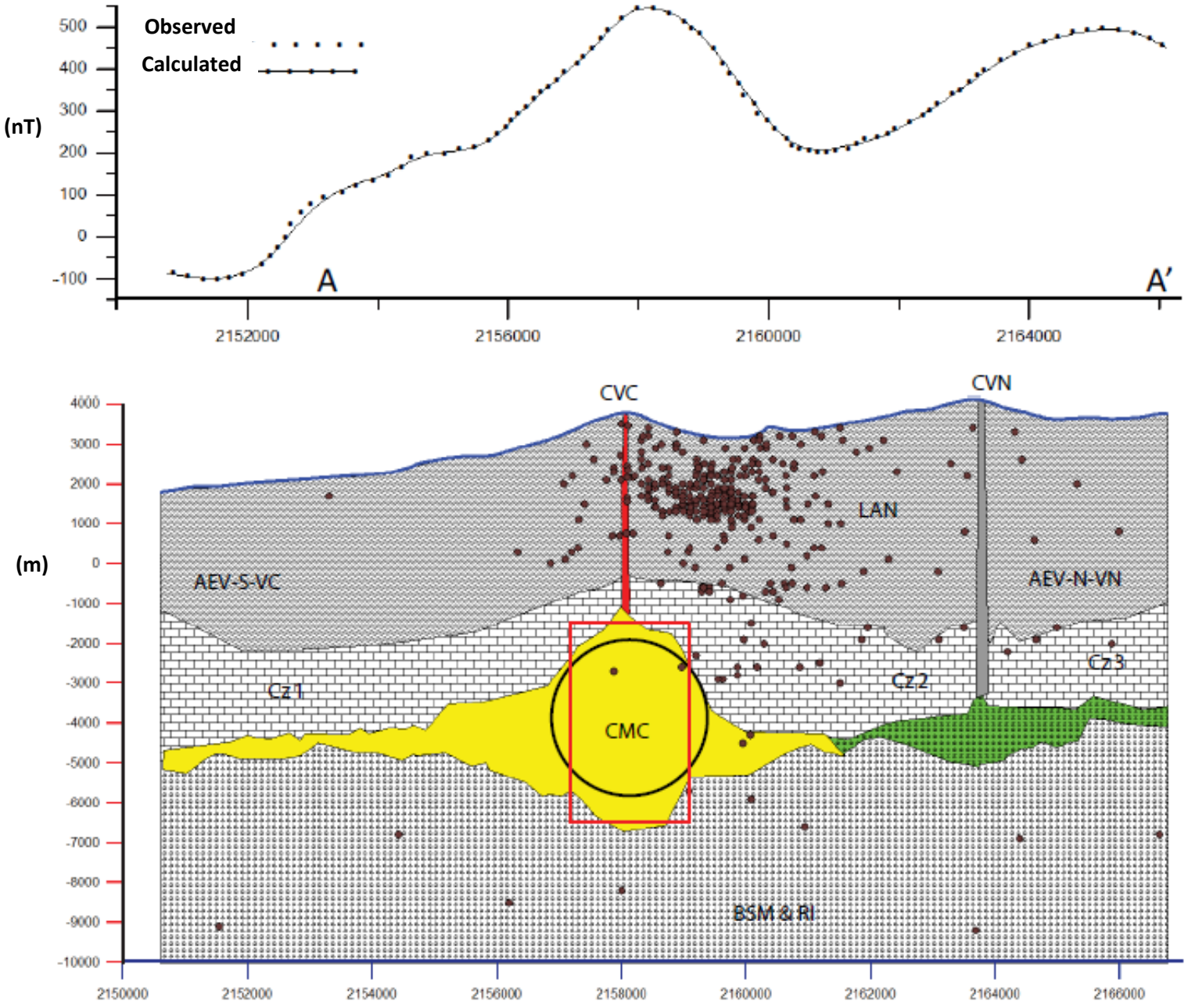


Colima volcanic complex
Reduced to the pole anomaly

Colima volcanic complex
Reduced to the pole anomaly



Reduced to the pole magnetic anomaly of Colima volcanic complex

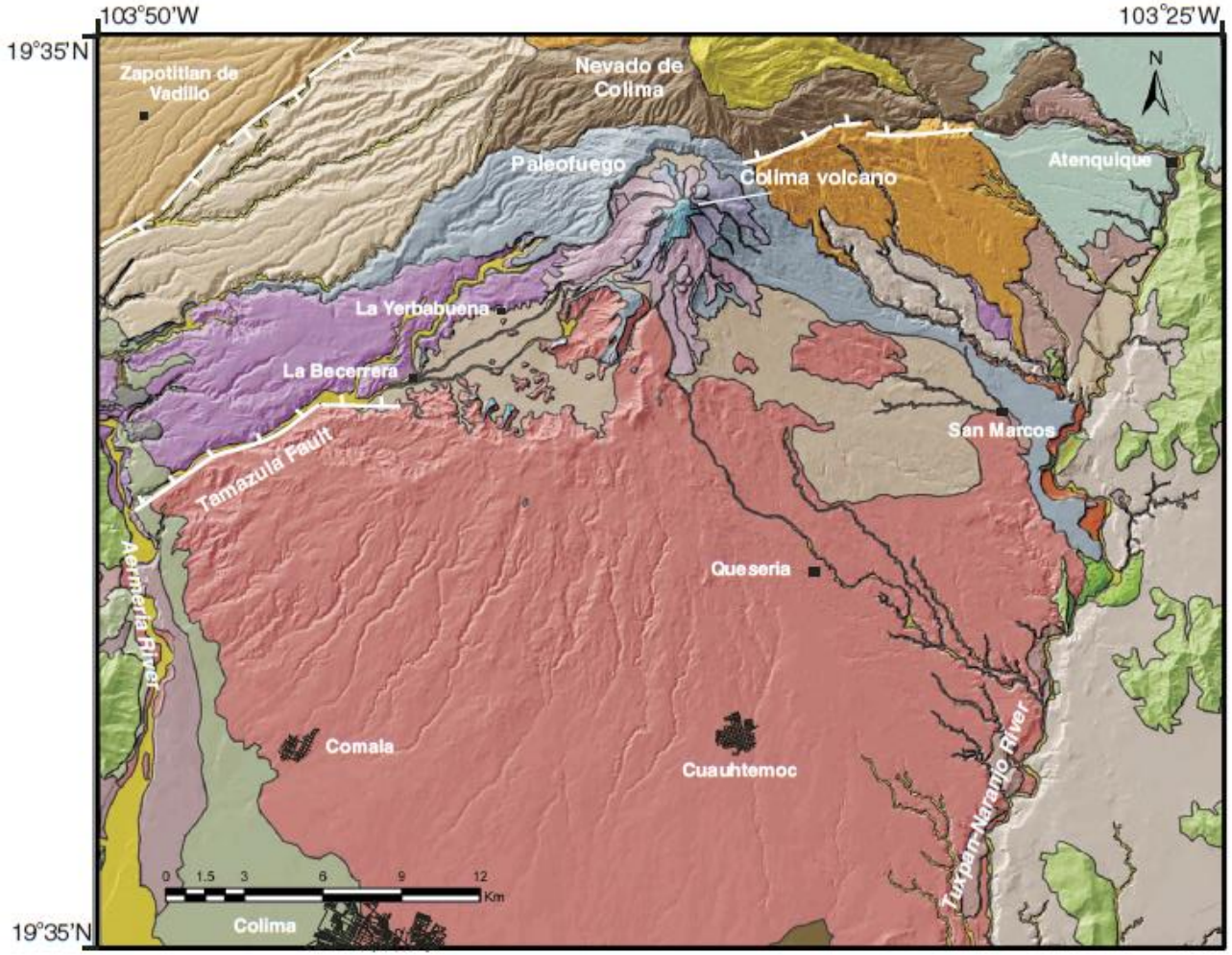


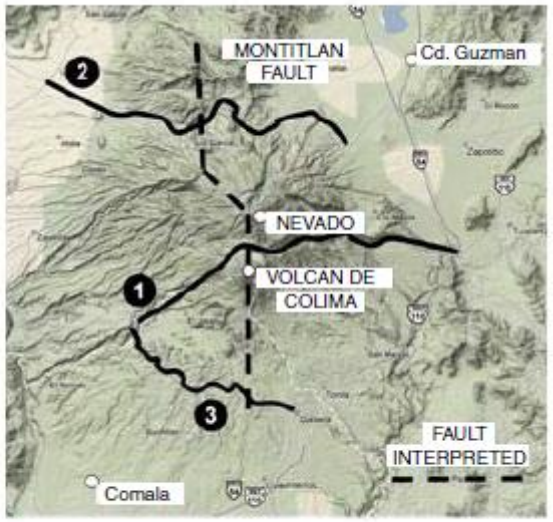
Structures affecting magnetic units

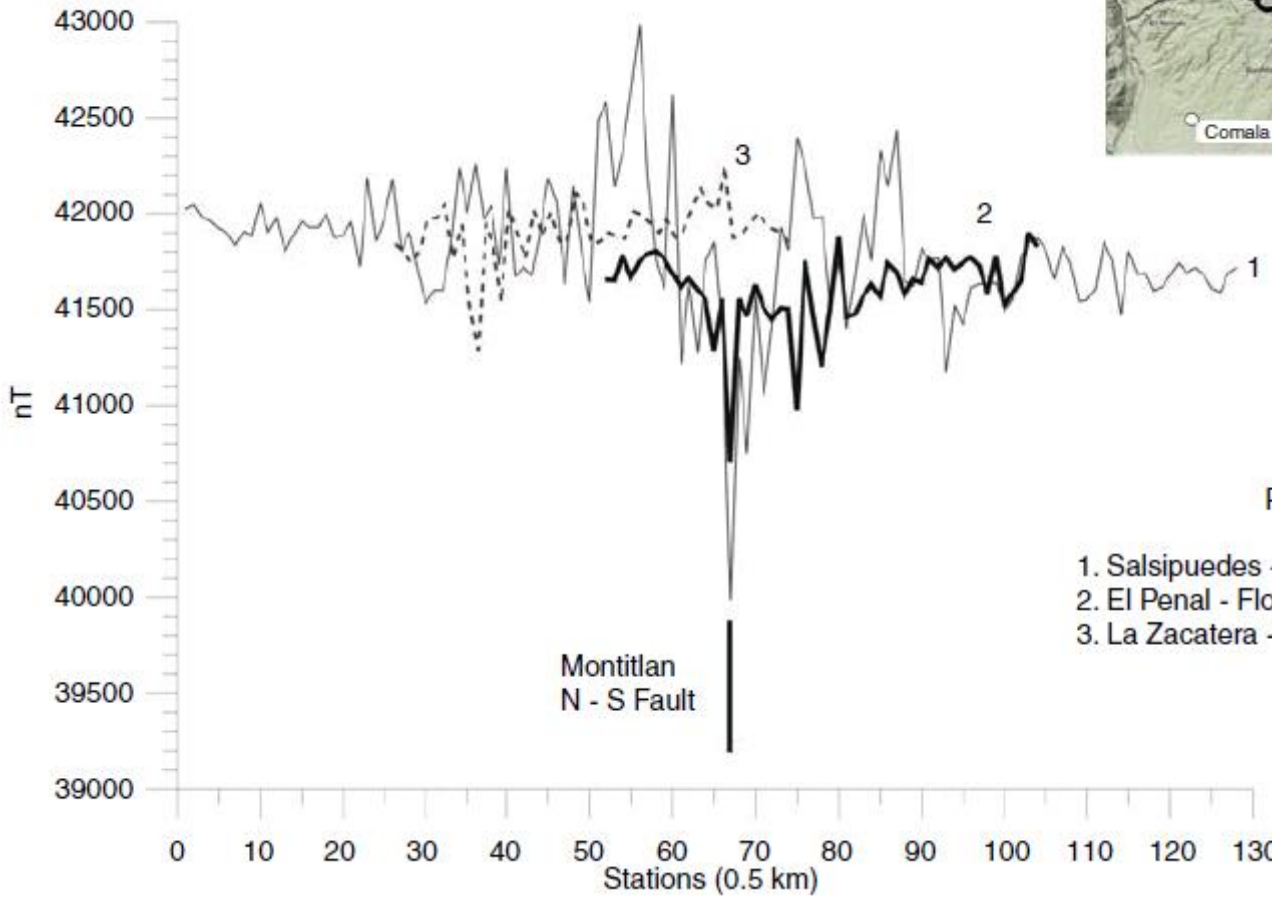
Faulting is recognized by:

- **offsets in apparently simila magnetic units,**
- **sudden discontinuities in magnetic units,**
- **abrupt changes of the dept magnetic units,**
- **linear magnetic lows, cause oxidation-weathering of magnetic units along a faul plane,**
- **linear magnetic highs, caus precipitation of magnetic minerals along a fault-plan**

Folding can be recognized by patterns of linear magnetic anomalies.

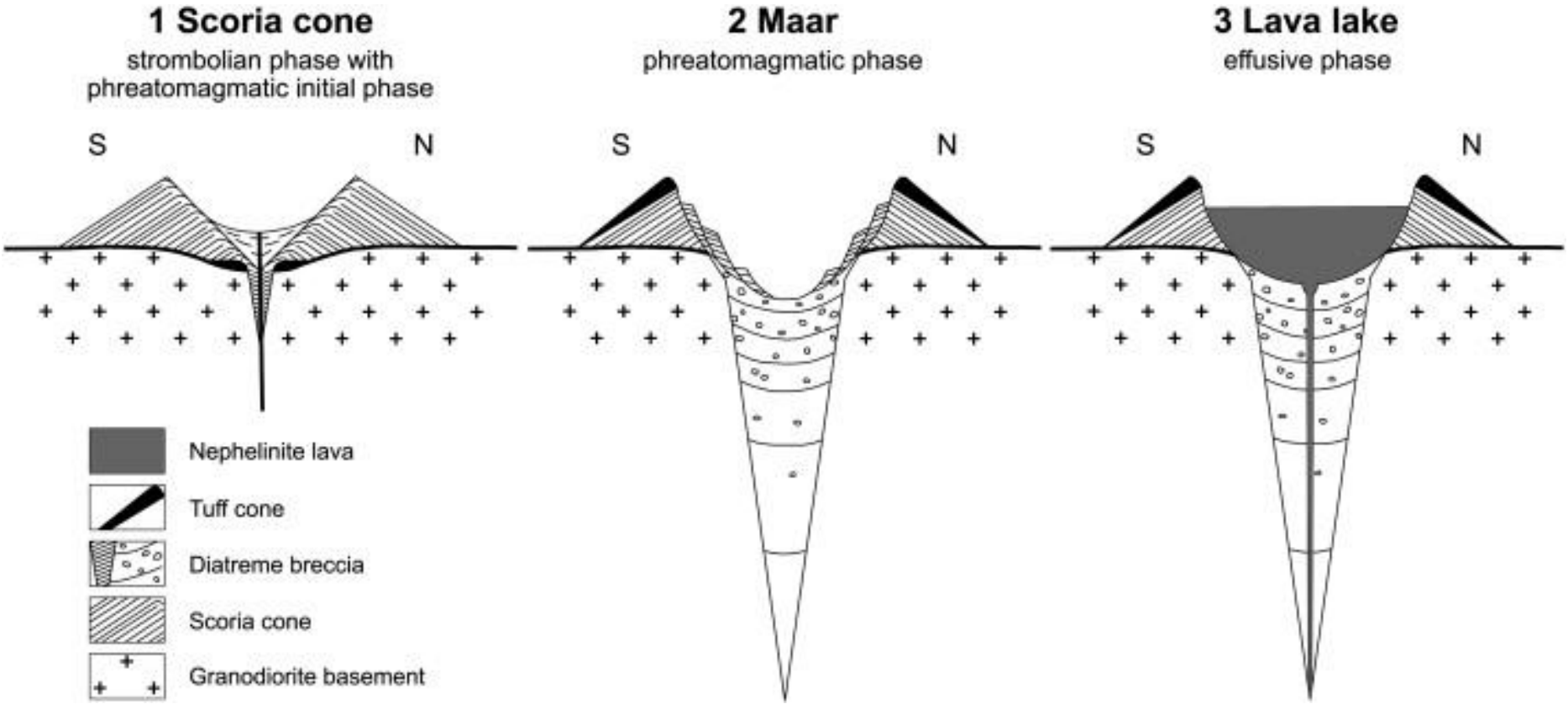


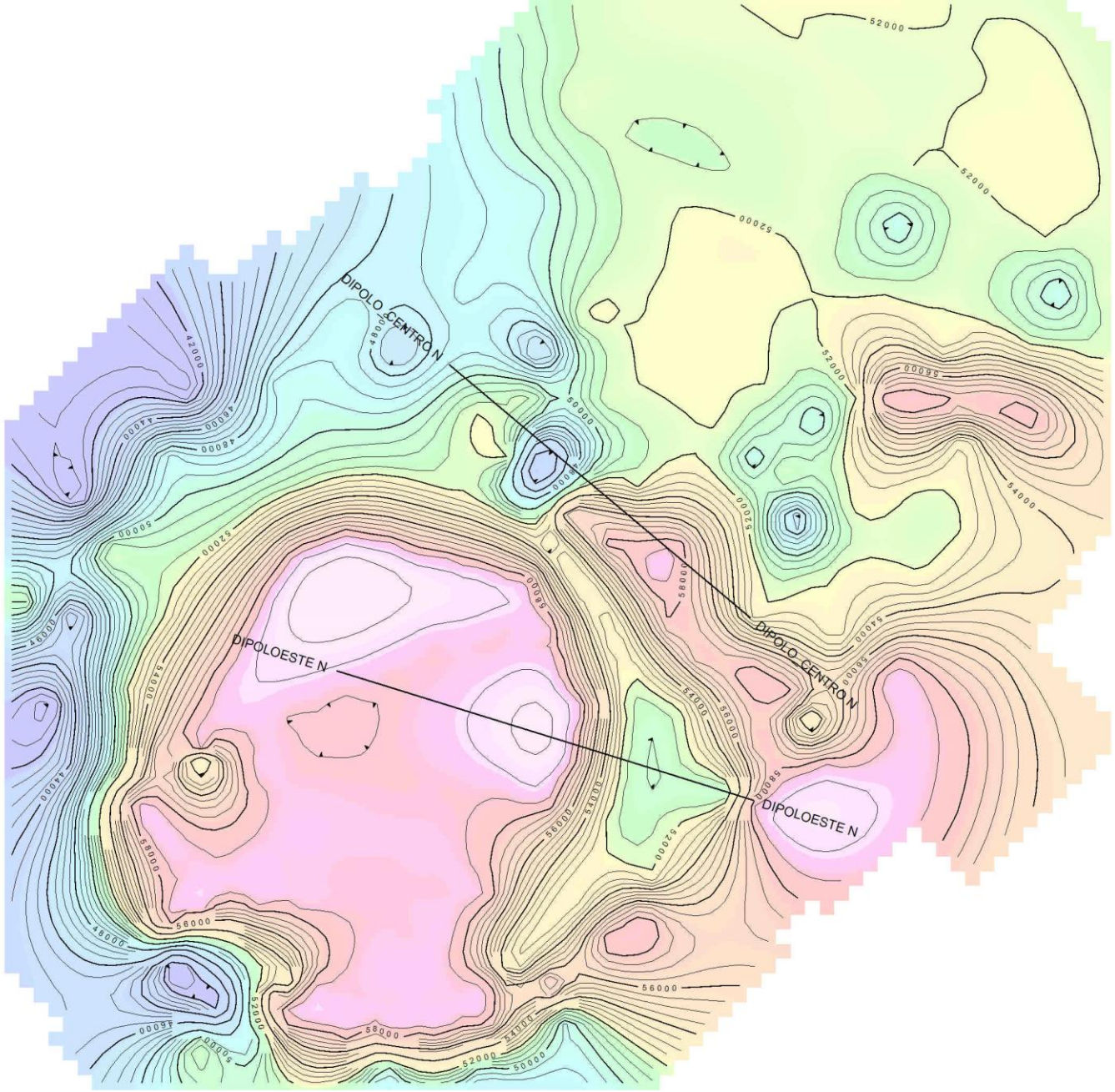


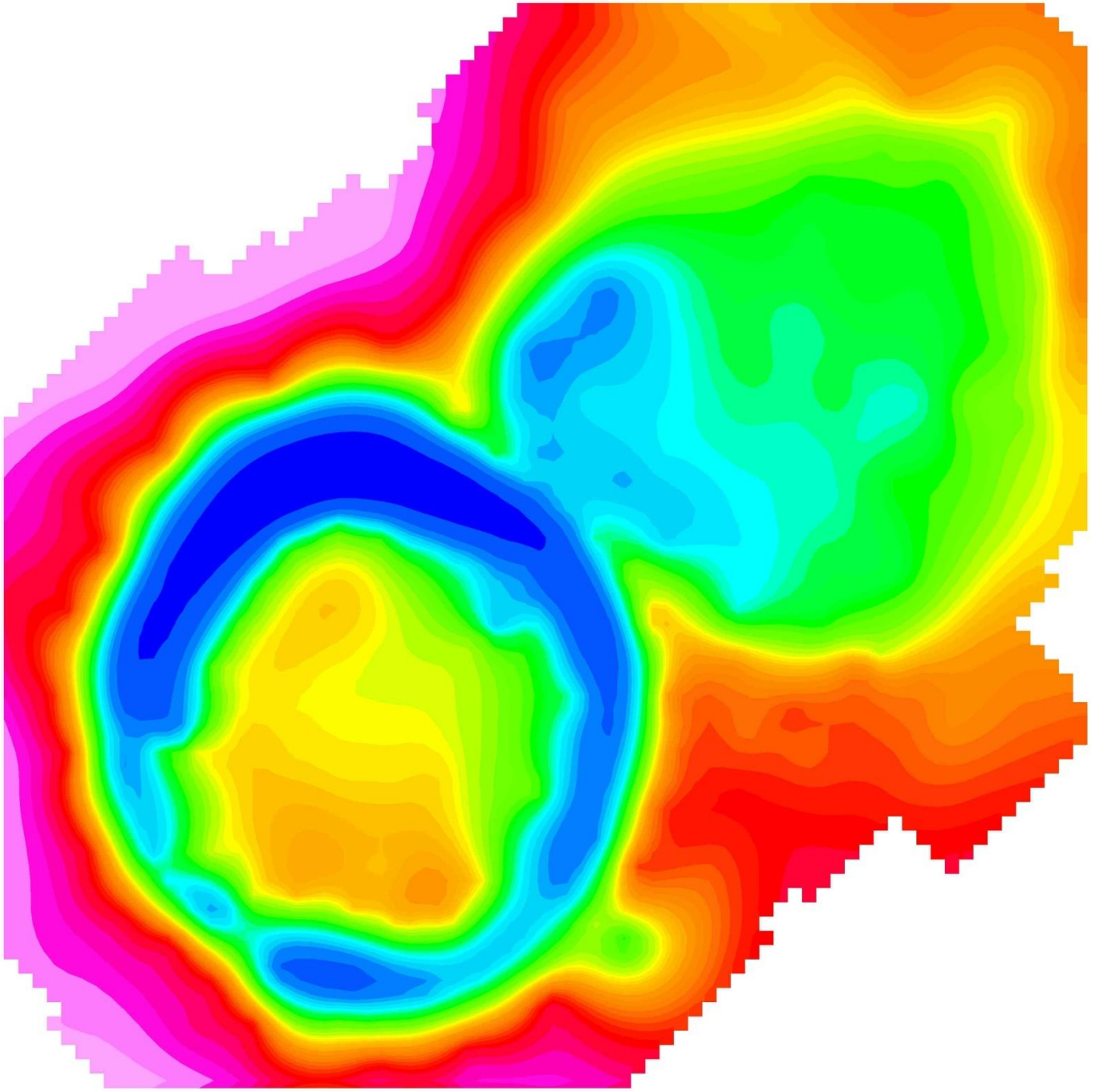


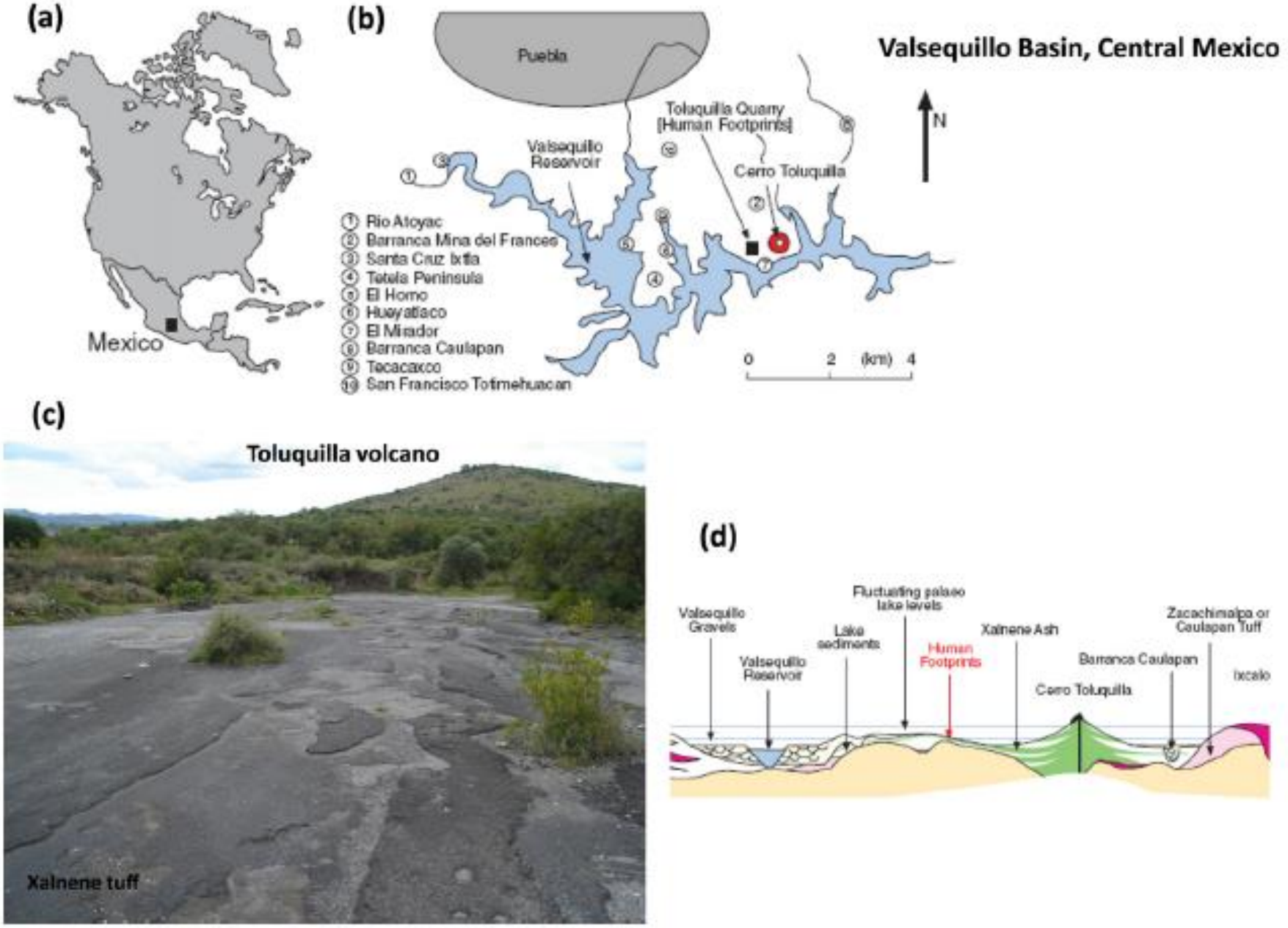
PROFILES

1. Salsipuedes - El Playon - Atenquique
2. El Penal - Floripondio - Cd. Guzman
3. La Zacatera - Montitlan - Queseria

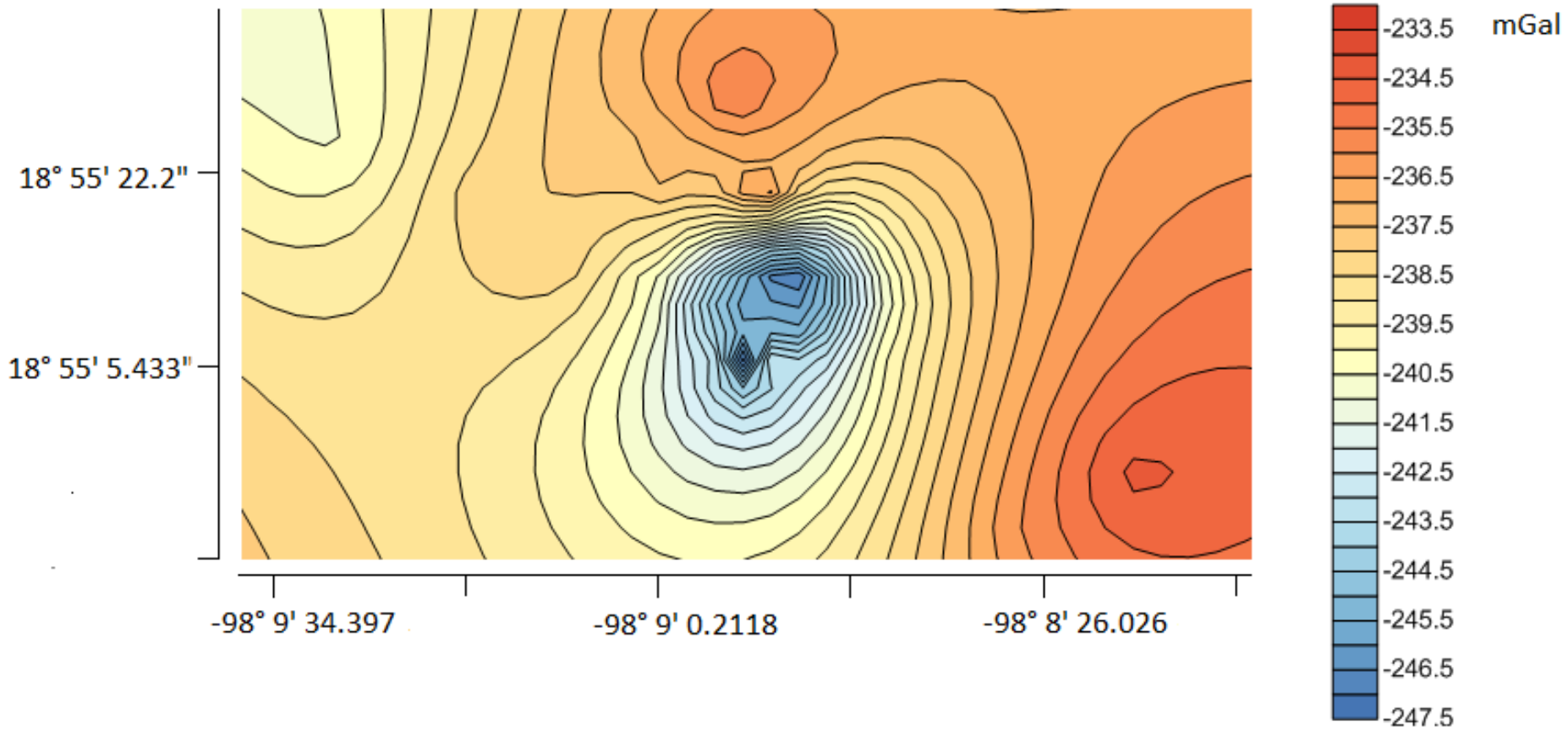

1 Scoria cone
strombolian phase with
phreatomagmatic initial phase
S
N
2 Maar
phreatomagmatic phase
S
N
3 Lava lake
effusive phase
S
N
Nephelinite lava
Tuff cone
Diatreme breccia
Scoria cone
Granodiorite basement


DIPOLO_CENTRO N
DIPOLOESTE N
DIPOLO_CENTRO N
DIPOLOESTE N



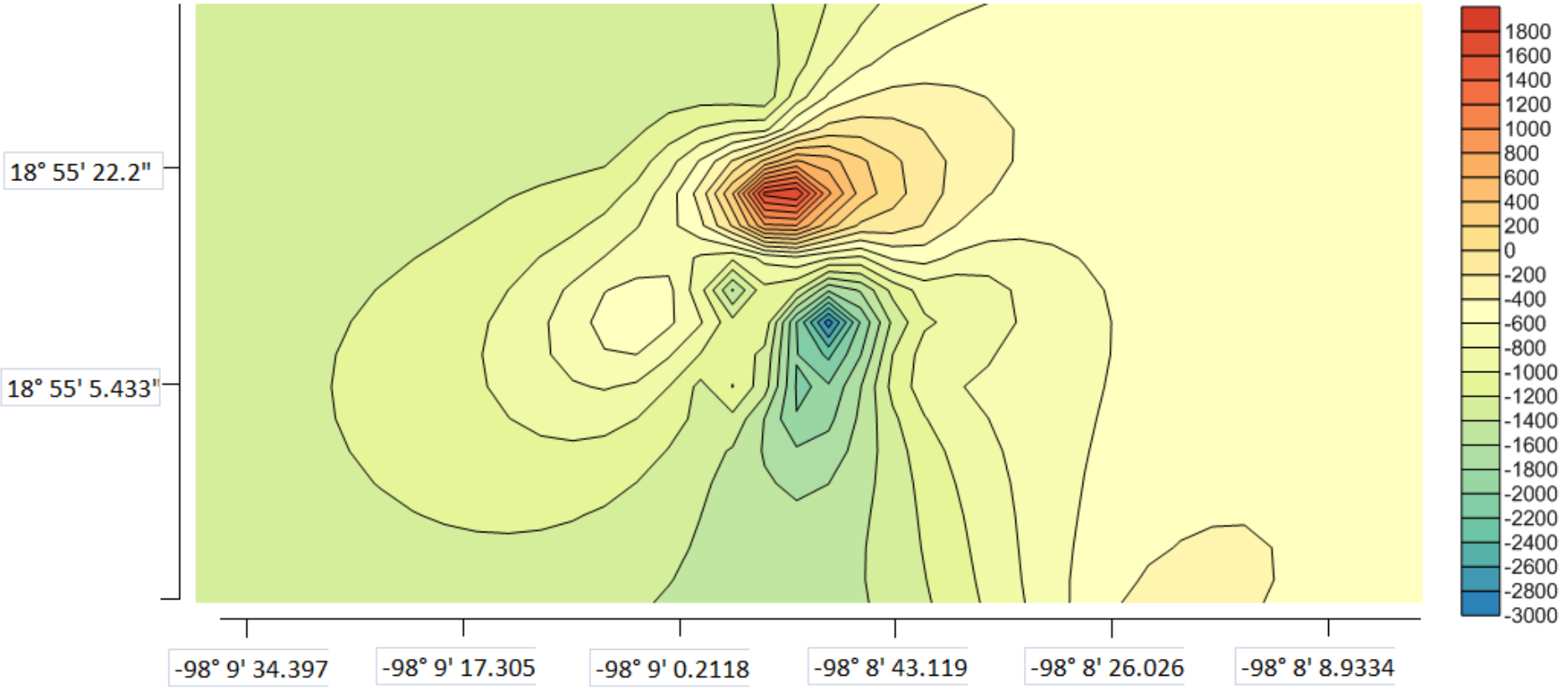

(a)
Mexico
(b)
Valsequillo Basin, Central Mexico
Puebla
Toluquilla Quarry
[Human Footprints]
Valsequillo
Reservoir
Cerro Toluquilla
N
1 Rio Atoyac
2 Barranca Mina del Frances
3 Santa Cruz Ixtla
4 Tetela Peninsula
5 El Horno
6 Huayatlaco
7 El Mirador
8 Barranca Caulapan
9 Tecacaxco
10 San Francisco Totimehuacan
0 2 (km) 4
(c)
Toluquilla volcano
Xalnene tuff
(d)
Valsequillo
Gravels
Valsequillo
Reservoir
Lake
sediments
Fluctuating palaeo
lake levels
Human
Footprints
Xalnene Ash
Cerro Toluquilla
Barranca Caulapan
Zacachimalpa or
Caulapan Tuff
Ixcalo

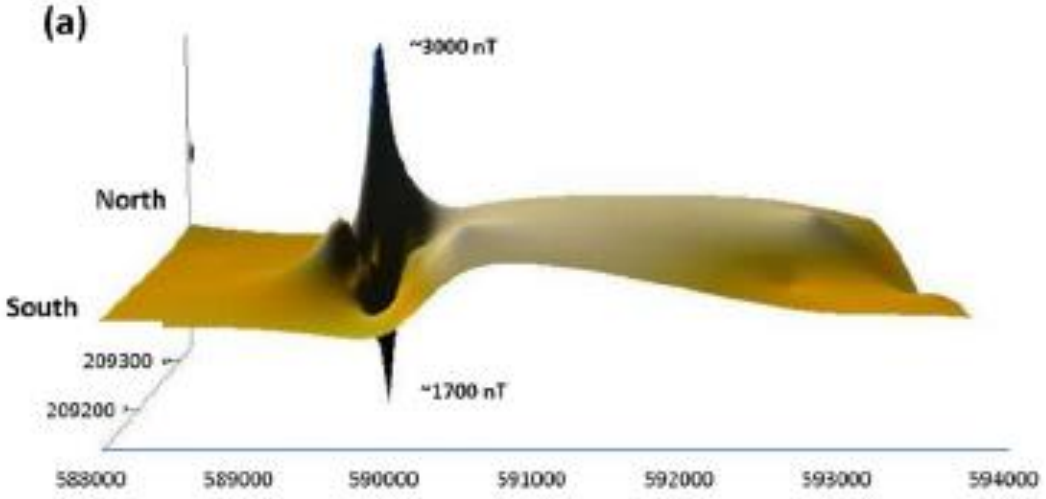
Volcán Toluquilla
Anomalía Gravimétrica
Coordenadas Geográficas

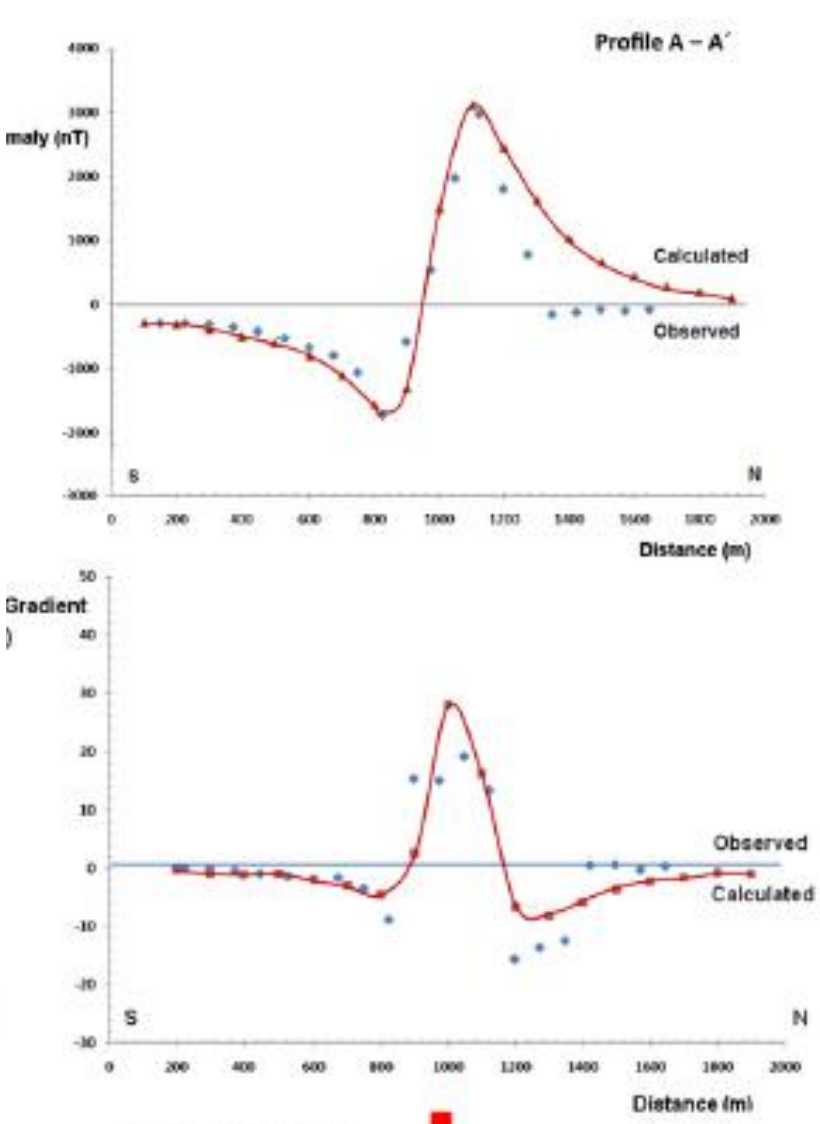


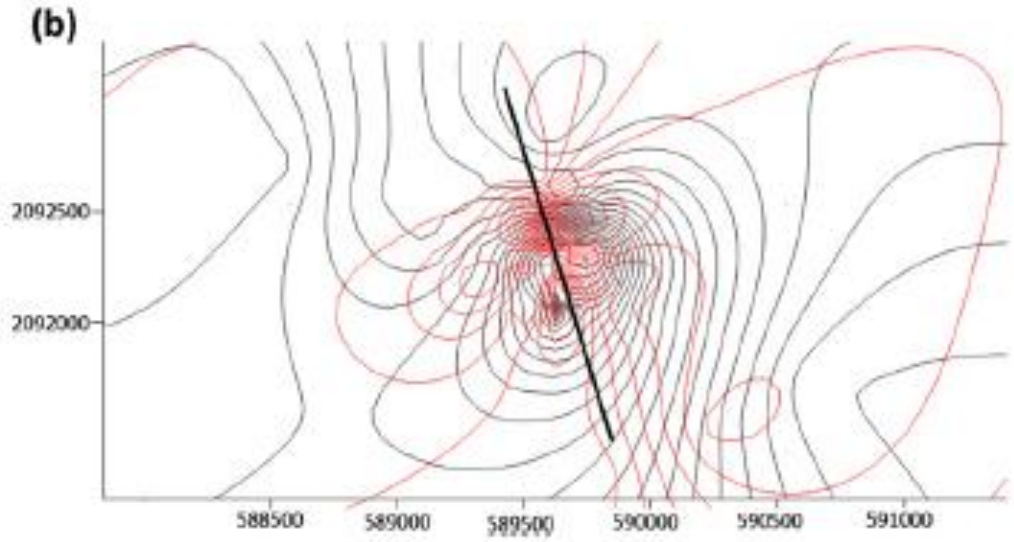
Volcán Toluquilla. Anomalía Magnética.

Coordenadas geográficas.



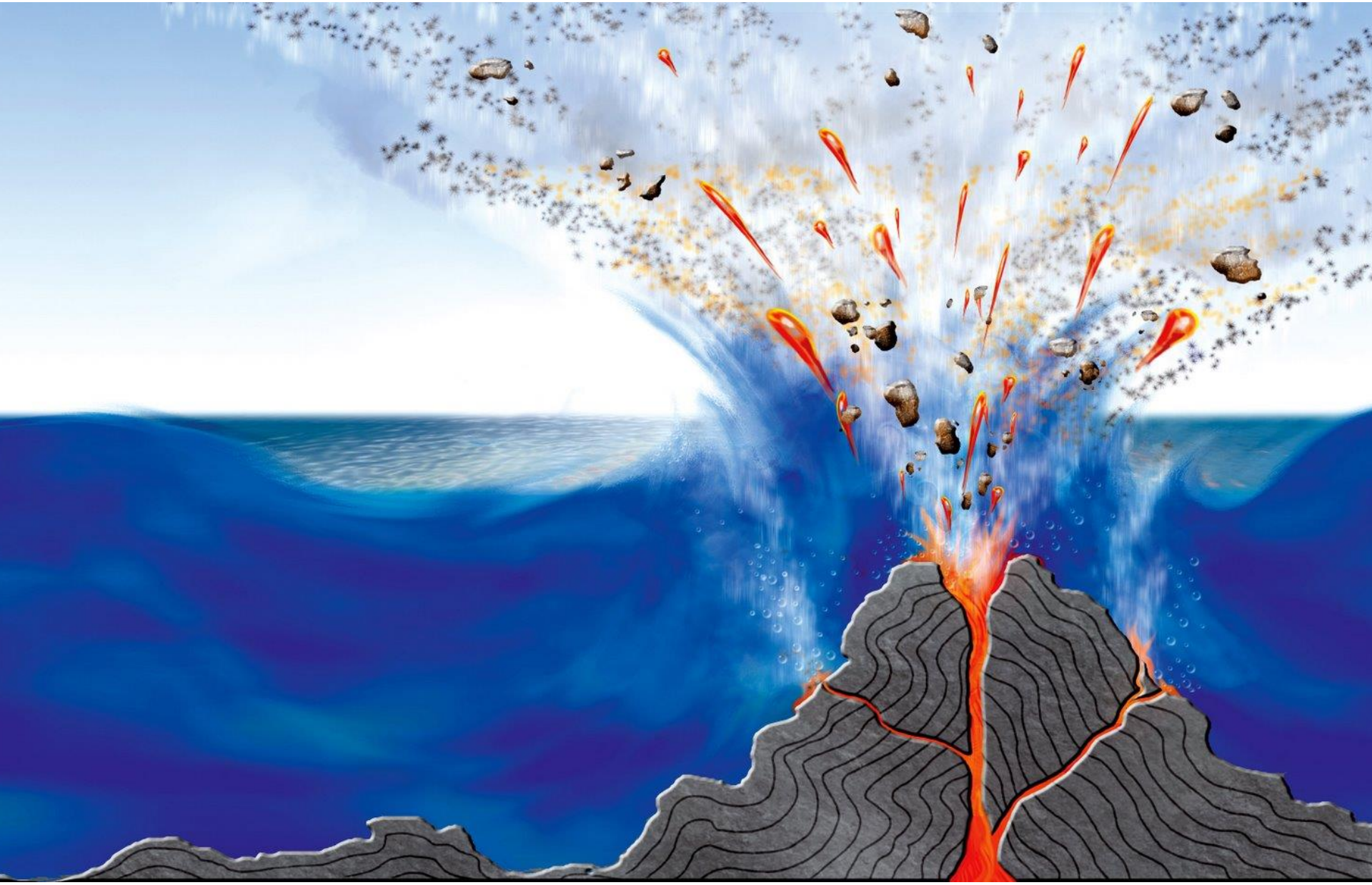


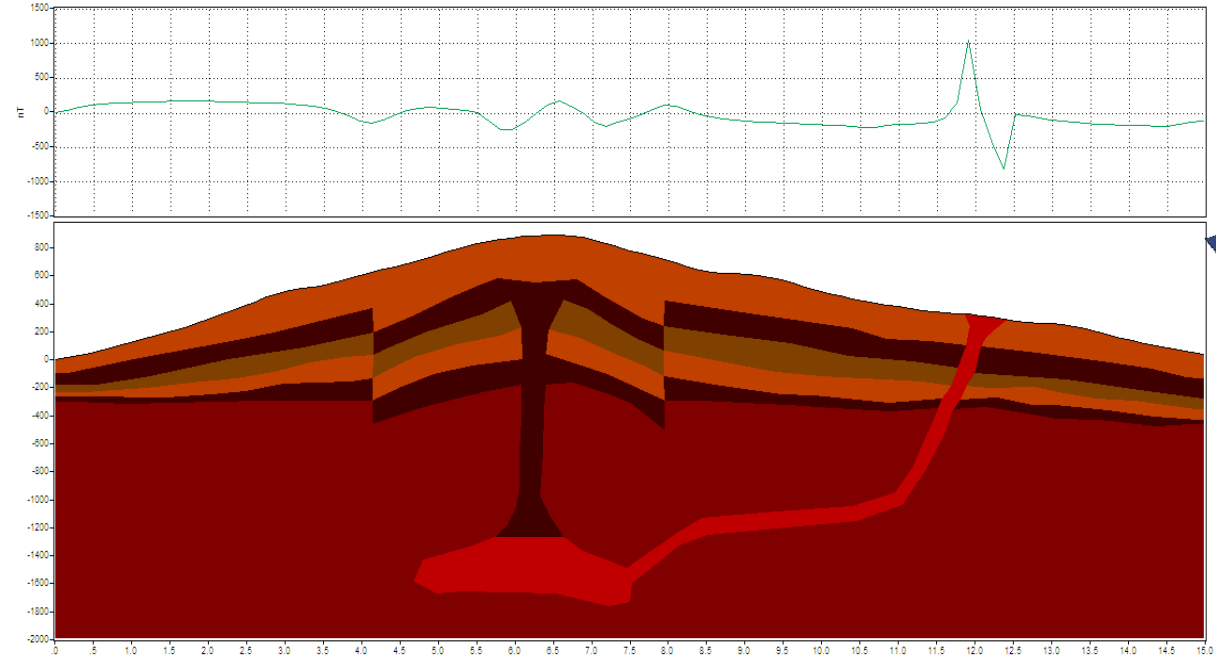


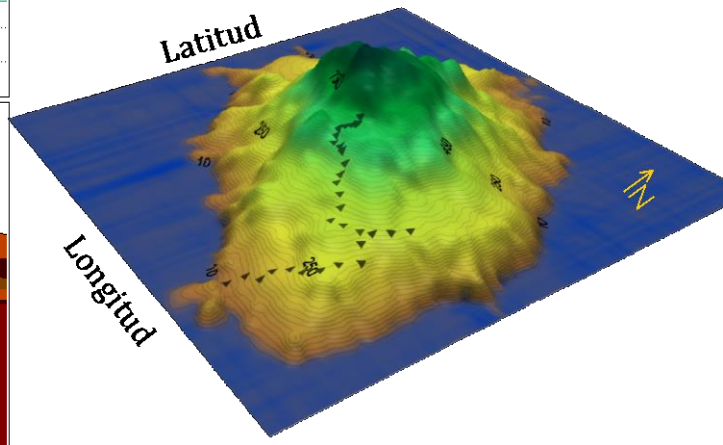


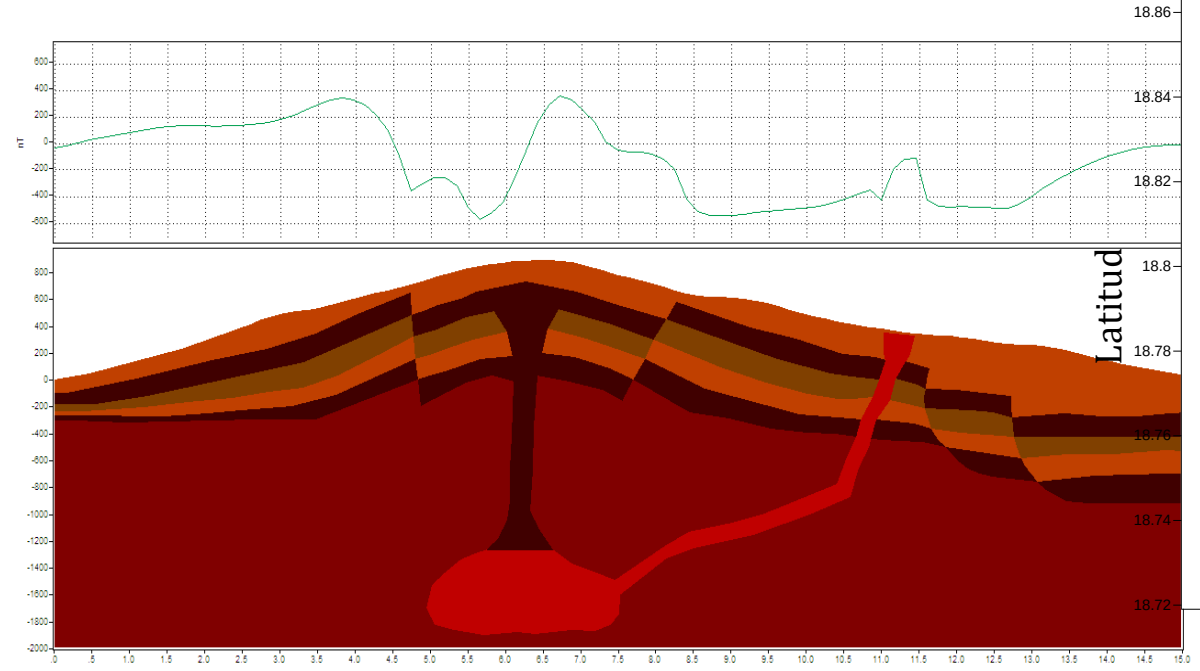
Prism Model Parameters
Depth to Top = 190 m
Width = 50 m
Strike length = 50 m
Vertical high = 1 km
H = 42000 nT
Decl = 175°
Incl = -42°

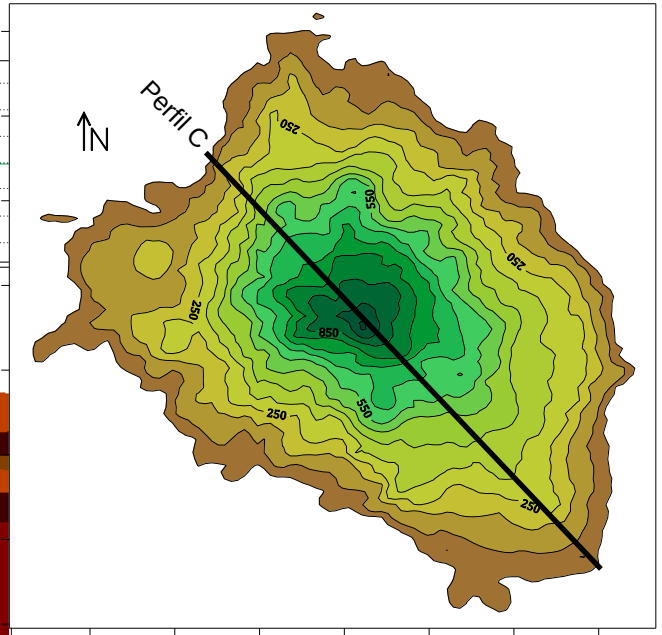
Toluquilla Volcano, Valsequillo Basin

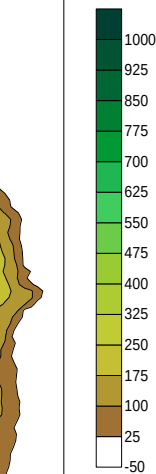


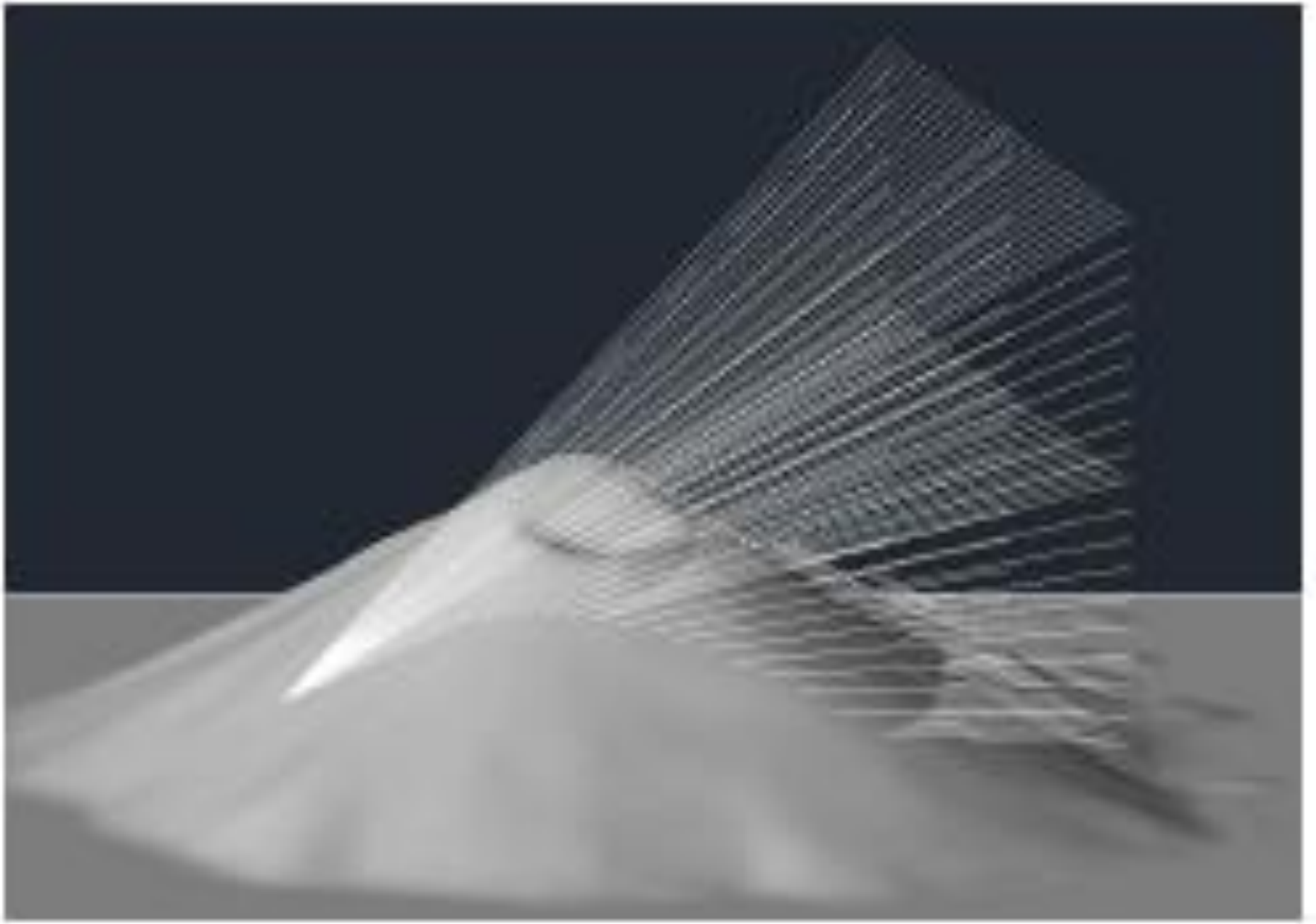



Latitud
Longitud
N


Latitud
18.86
18.84
18.82
18.8
18.78
18.74
18.72


Perfil C
N
250
550
850
-111.04
-111.02
-111
-110.98
-110.96
-110.94
-110.92
Longitud


[m]
1000
925
850
775
700
625
550
475
400
325
250
175
100
25
-50



Simulation for muon detector on the Popocatepetl volcano

Iluminación cósmica

1 Todos los días llegan a la Tierra partículas provenientes del Sol y otras estrellas, las cuales bombardean, literalmente, todos los cuerpos en el planeta pero son tan pequeñas que no se perciben.

Partículas celestes

2 Al entrar en contacto con la atmósfera, los núcleos reaccionan y producen una cascada de nuevas partículas inestables llamadas piones.

ATMÓSFERA

Piones

3 Estas minúsculas partículas se transforman en otras partículas elementales, entre ellas los muones, que son 200 veces más pesados que un electrón común.

4 Es posible detectarlos con equipos especiales llamados centelladores. Dependiendo de la intensidad que tengan los muones al llegar al detector, generan una imagen del interior del volcán.

Muones
Viajan a una velocidad cercana a la de la luz y tienen una vida muy corta, pero suficiente como para penetrar kilómetros de tierra.

Detector de muones

20 m

20 m

Trampa de muones

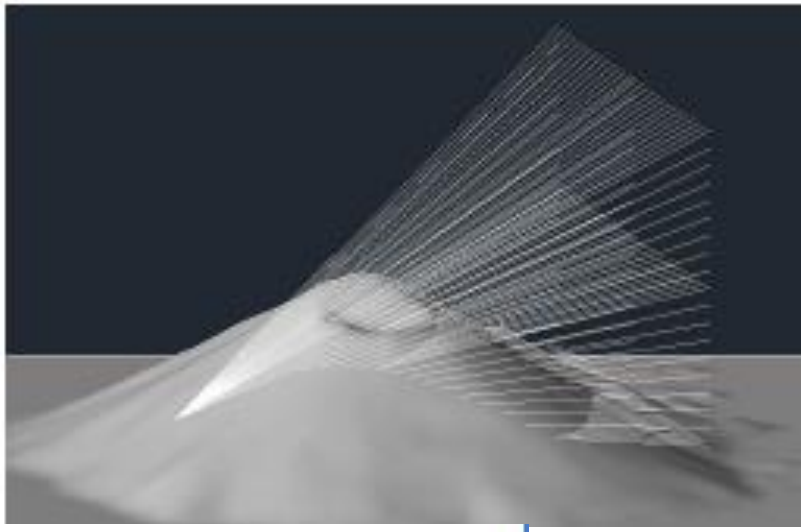
Para detectar las partículas, los especialistas requieren de un nuevo tipo de herramienta, que, en este caso, es una especie de trampa que se colocará en una de las laderas del volcán.

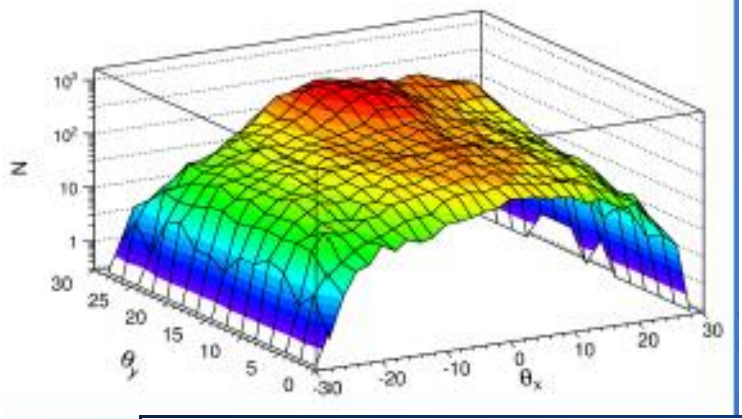
Tubo de PBC

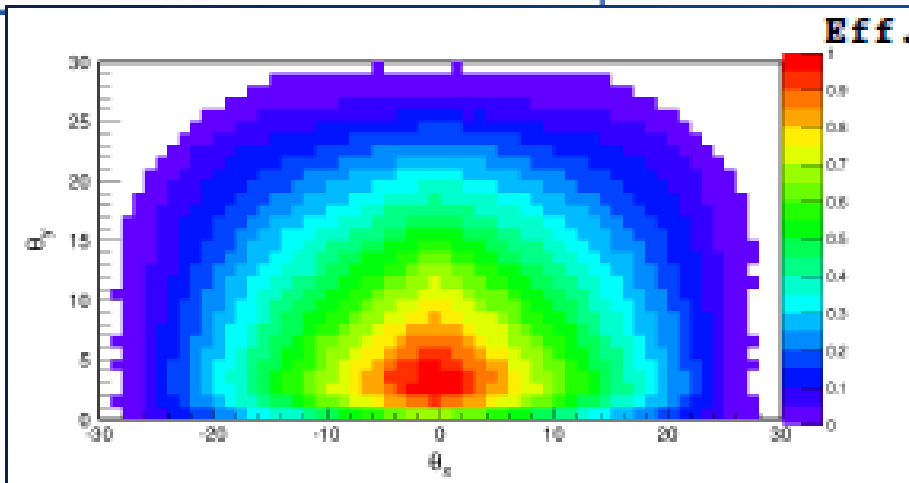
Líquido centellador especial para la detección de partículas

Plástico especial

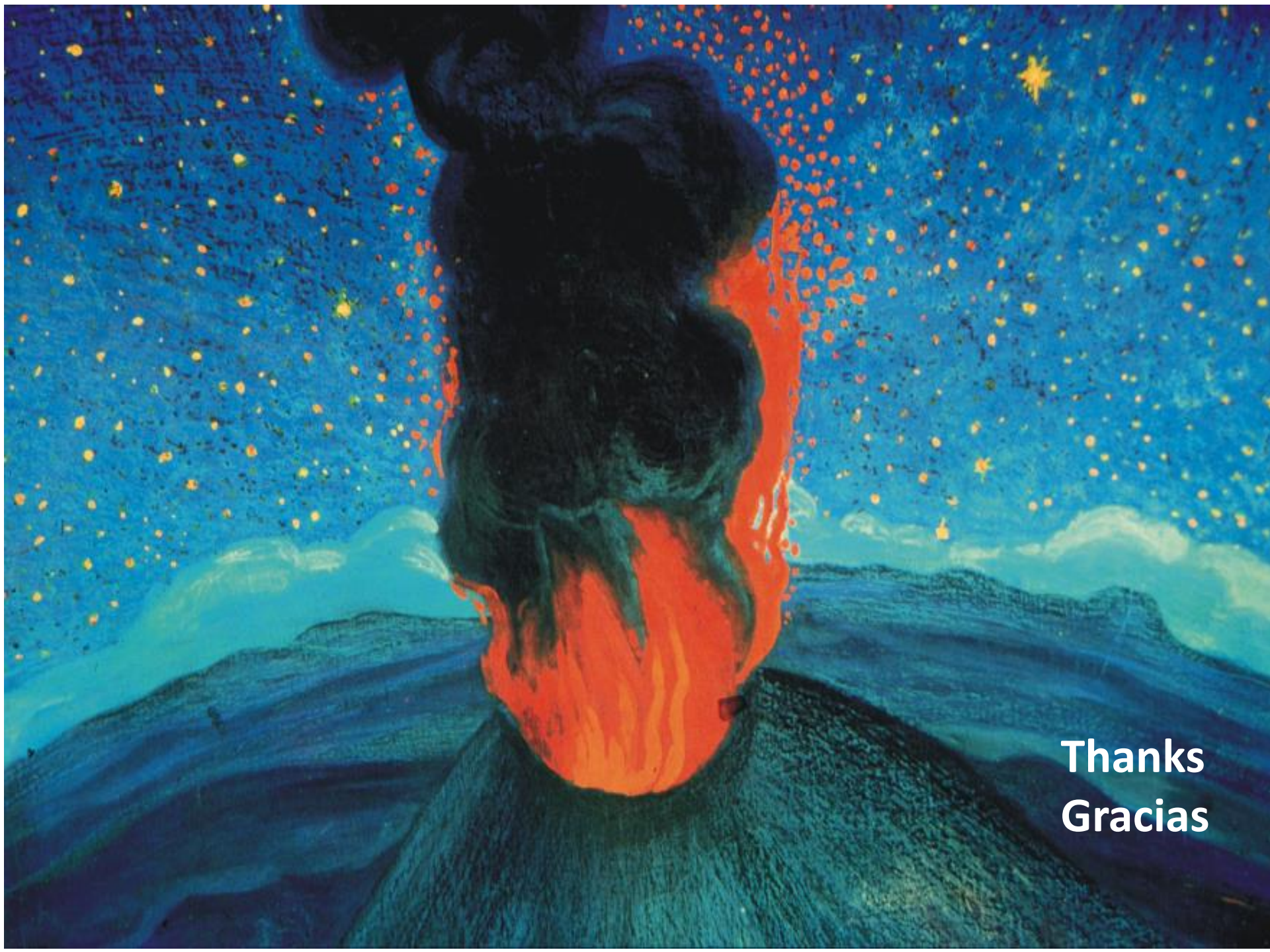
En cada punto de conexión contará con cableado especial para captar las señales que se generen dentro de los tubos.








Gracias


Thanks
Gracias